Nuclear Power

THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

Zirconium offers a combination of useful properties very attractive to the nuclear engineer.

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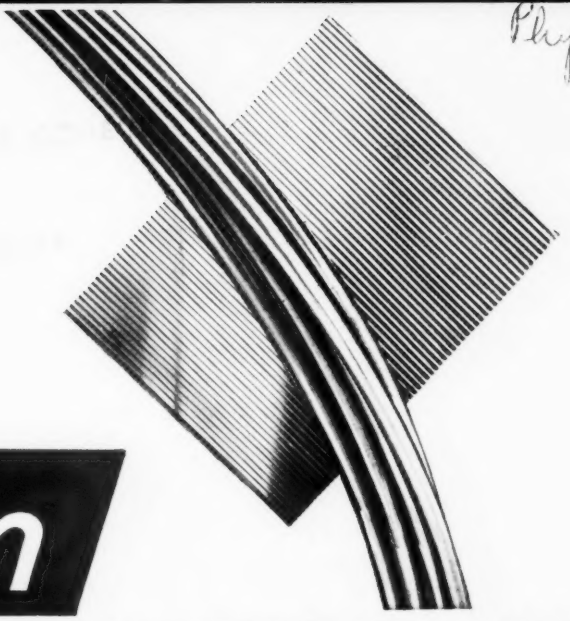

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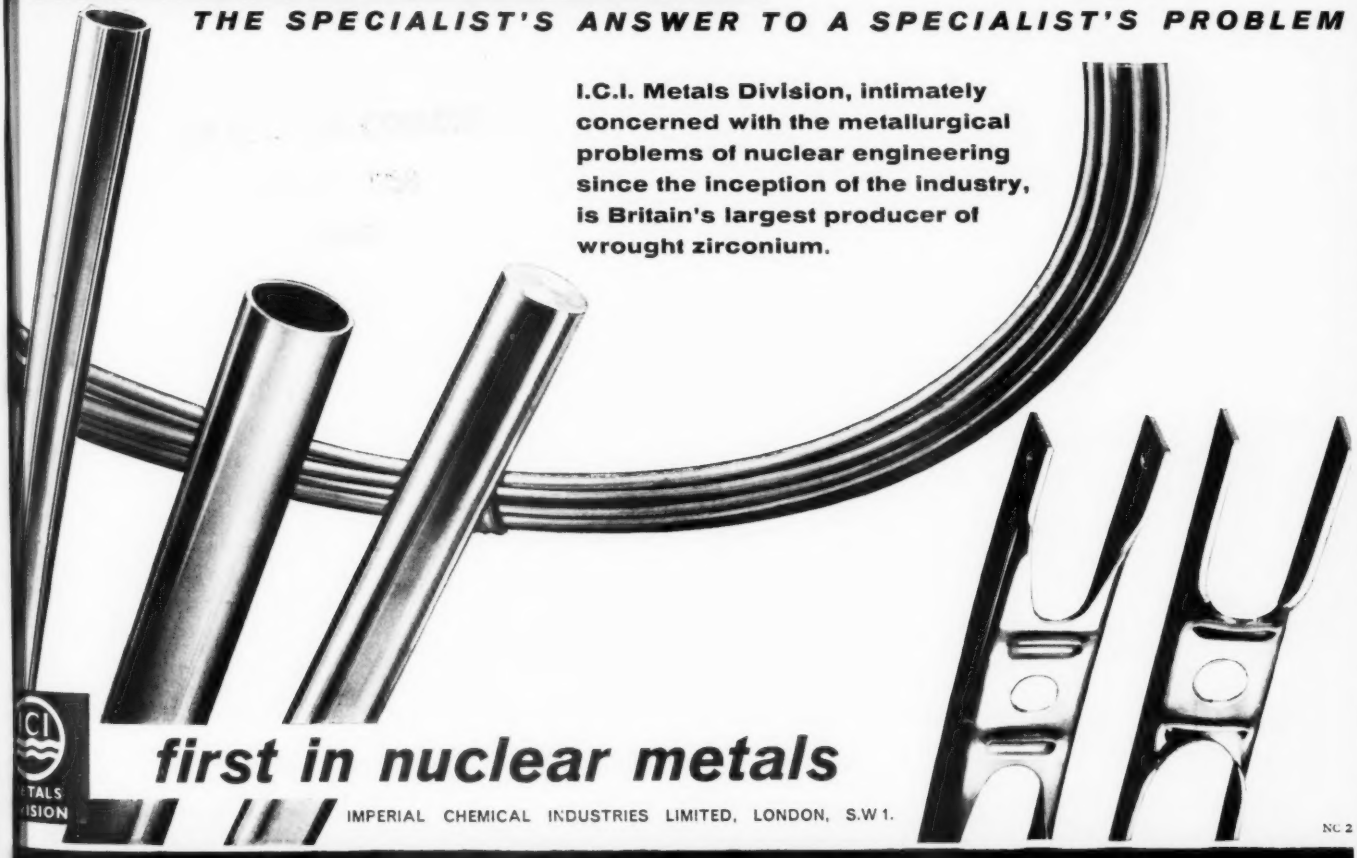

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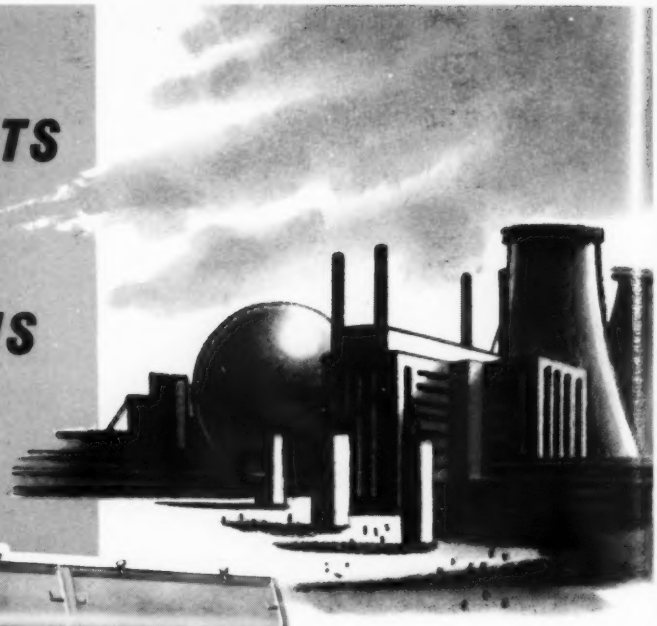
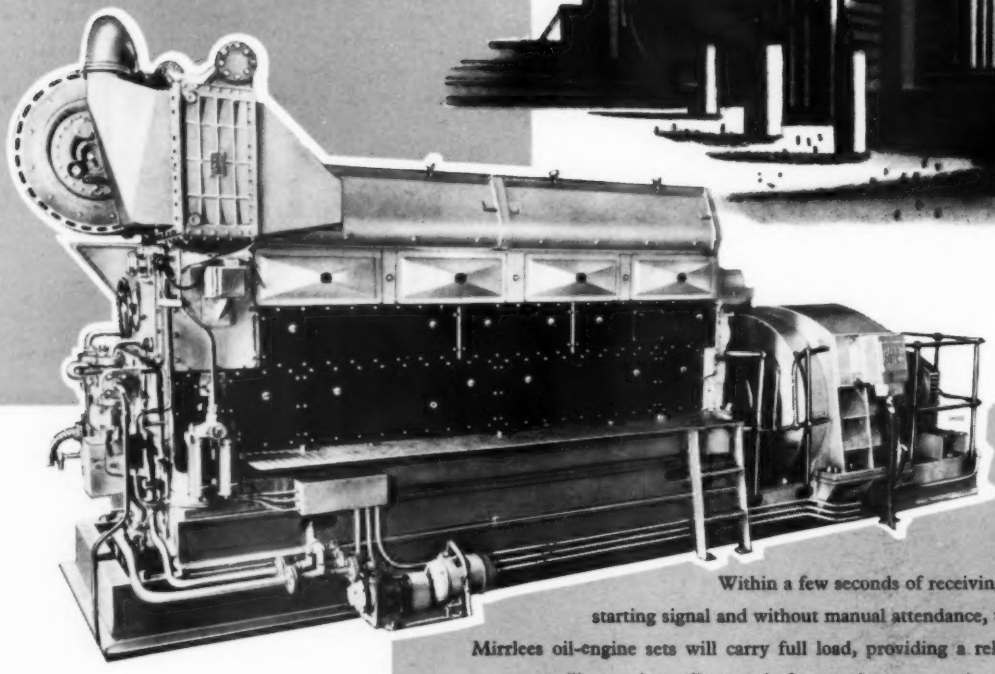
with automatic starting
FOR ATOMIC POWER STATIONS





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Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

DECEMBER 1958 VOLUME 3 NUMBER 32

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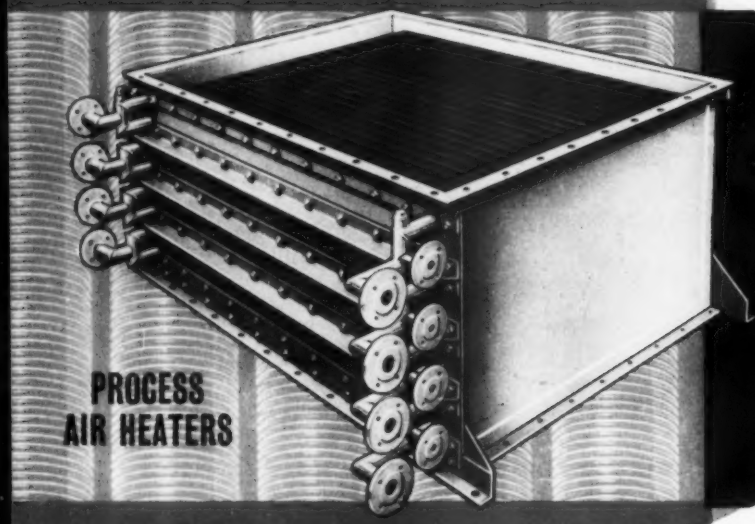

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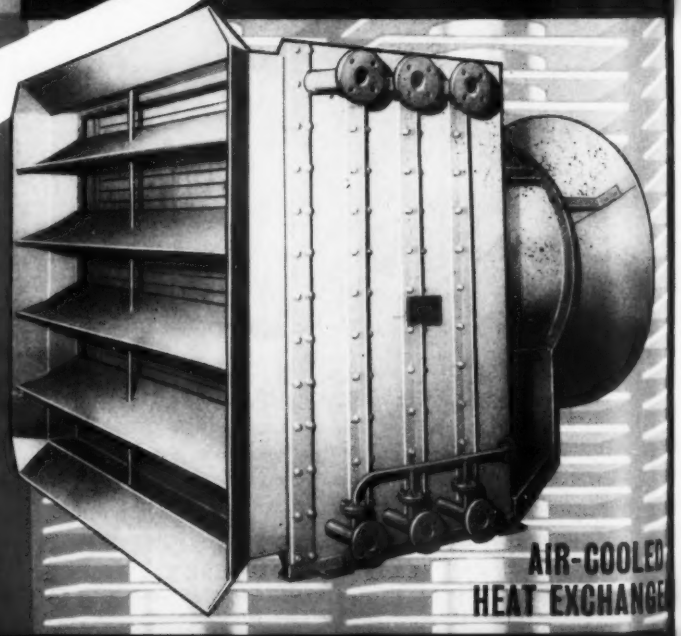

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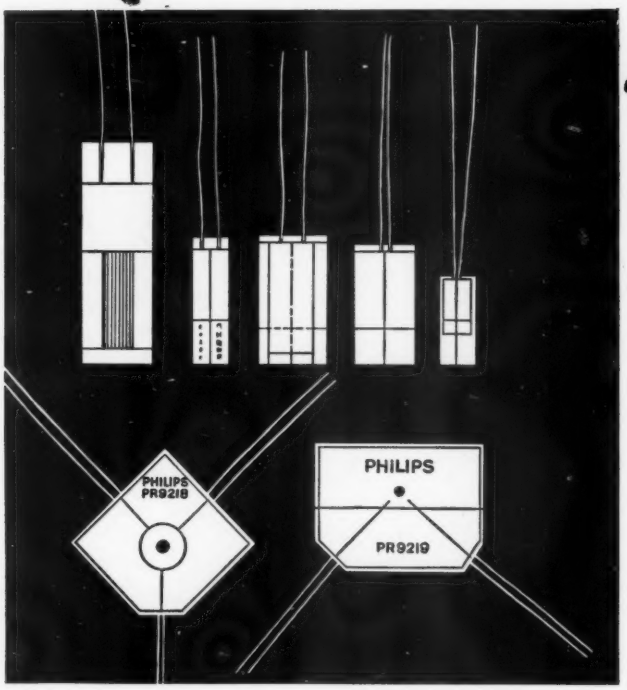

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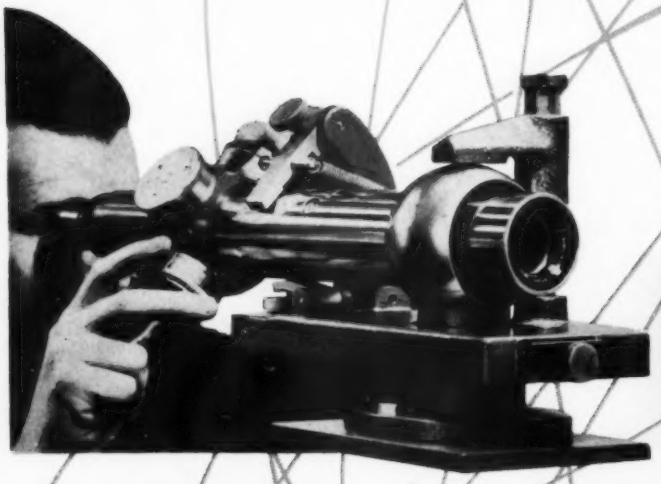

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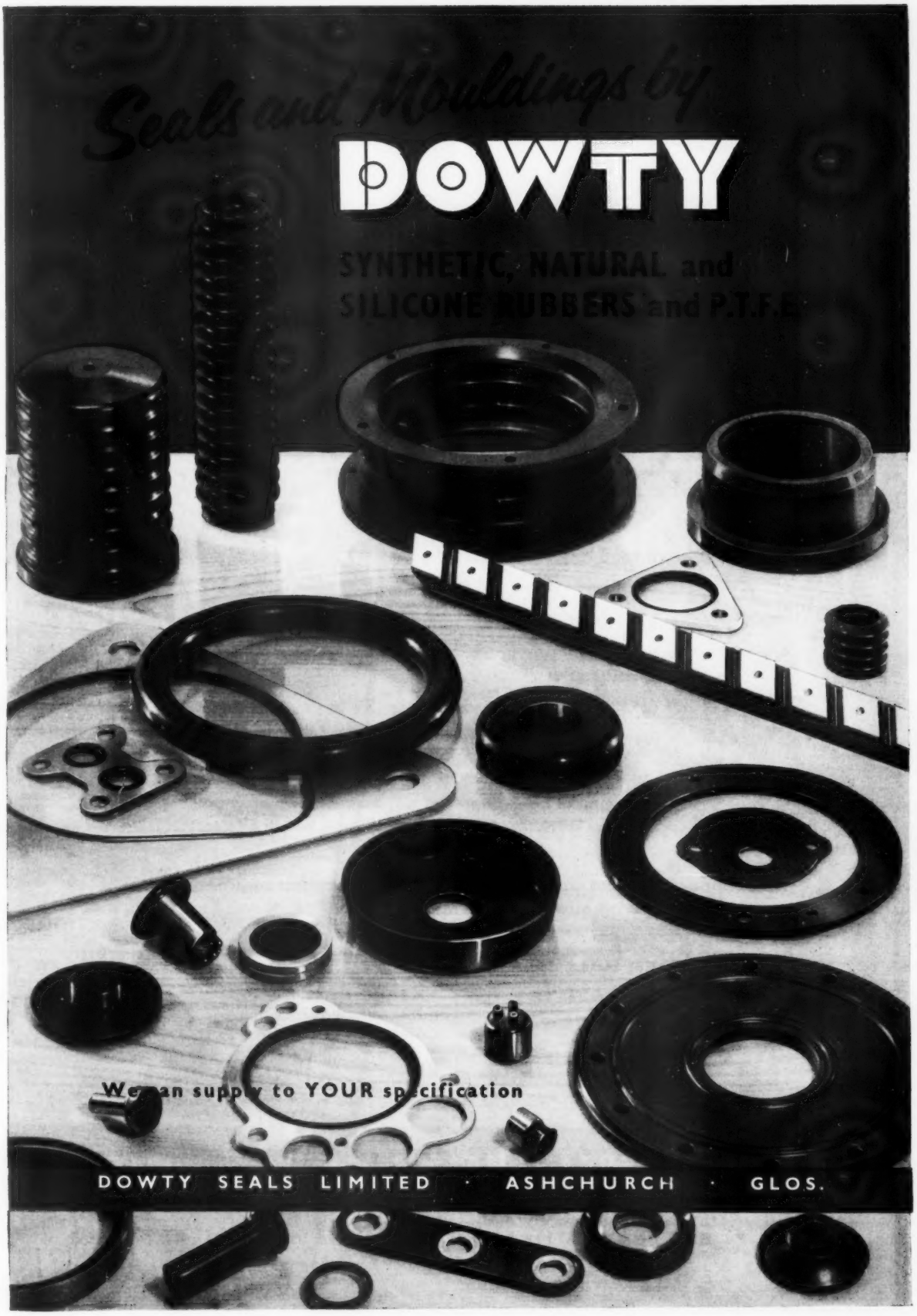
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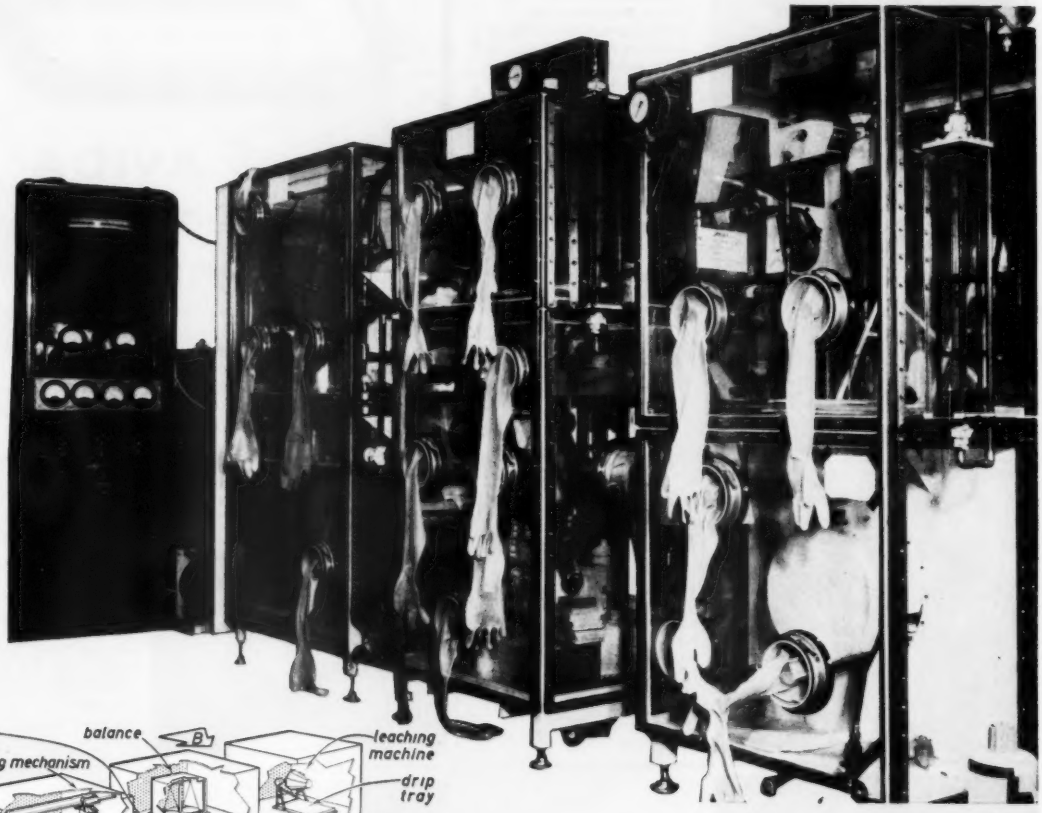

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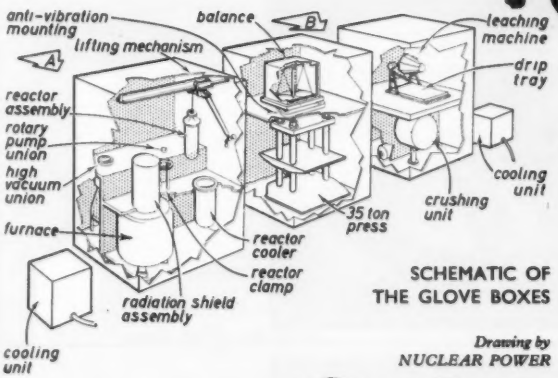
A SUITE OF GLOVE BOXES FOR EXPERIMENTAL PRODUCTION OF U-233 METAL



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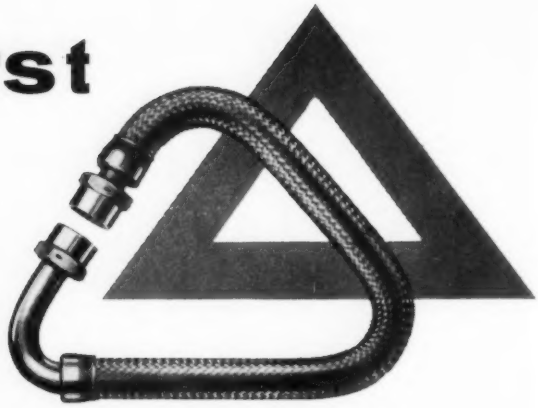

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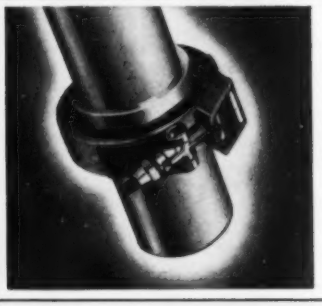

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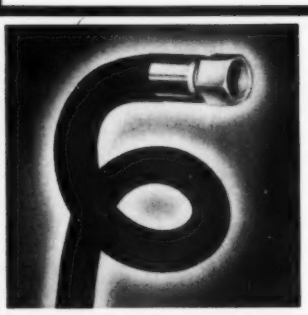

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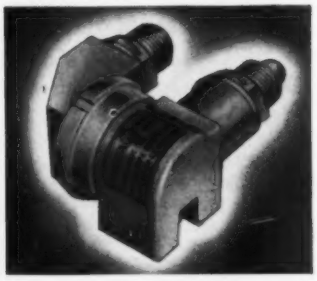

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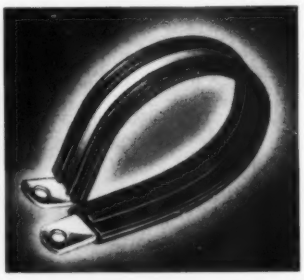

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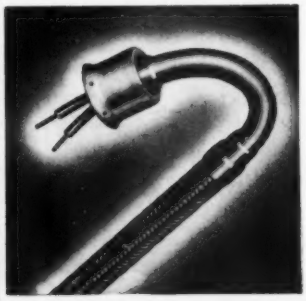

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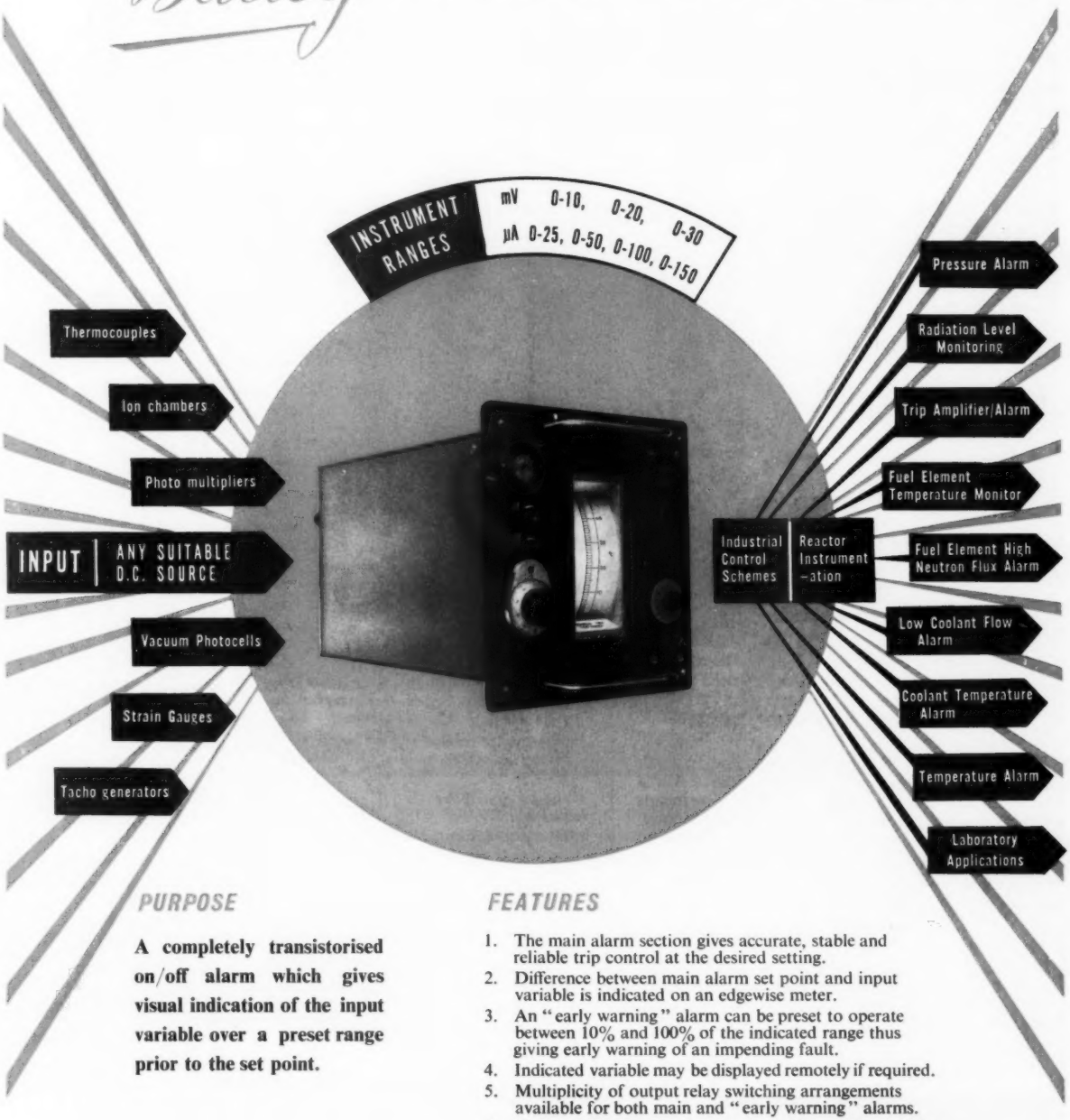

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- ★ **TRACES radio-active material in chemical analytic processes.**
- ★ **MEASURES contamination of any resulting effluent.**

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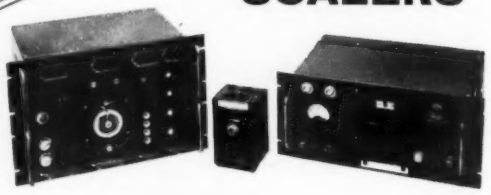

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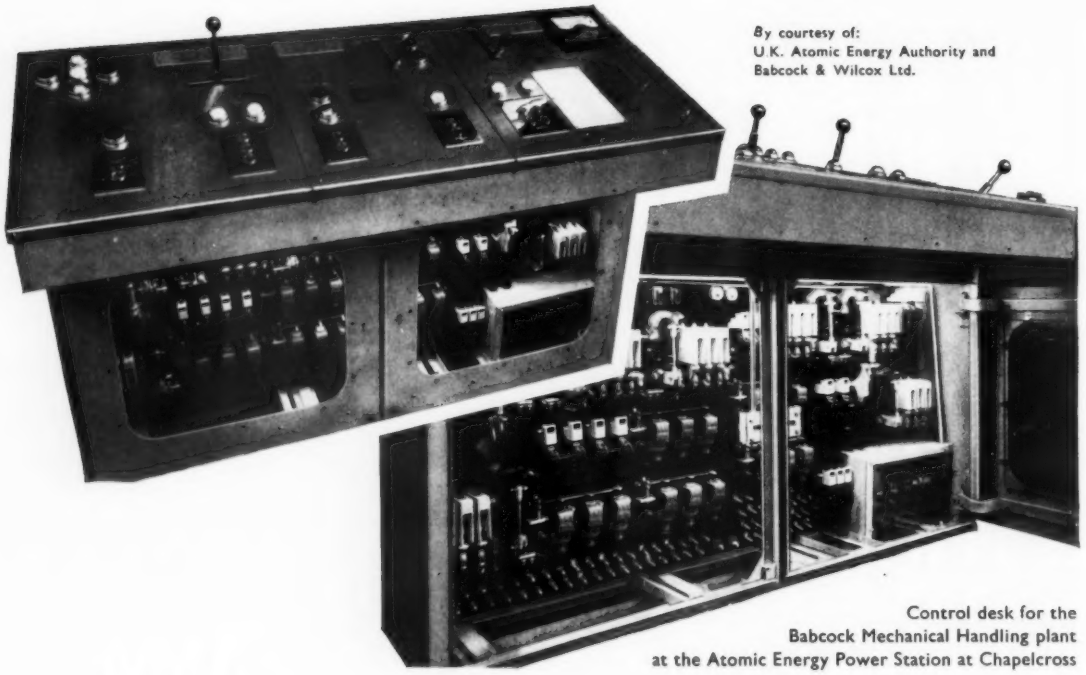

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EMB at Chapelcross

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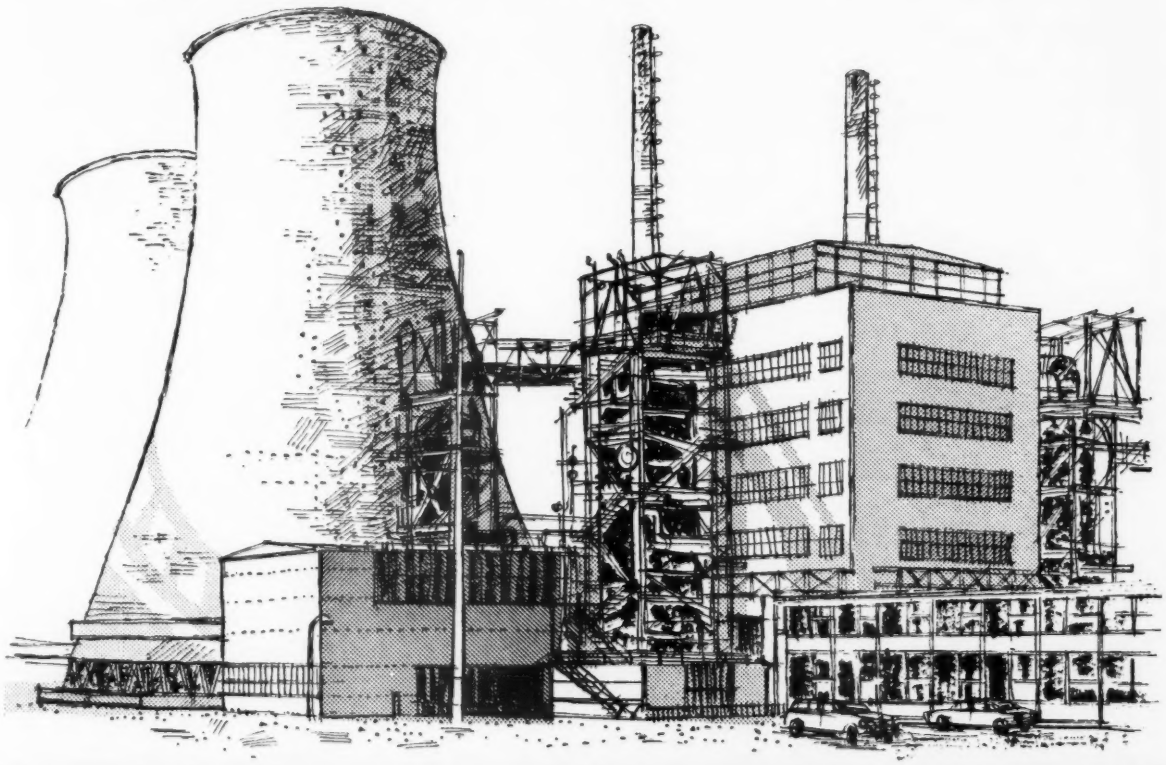

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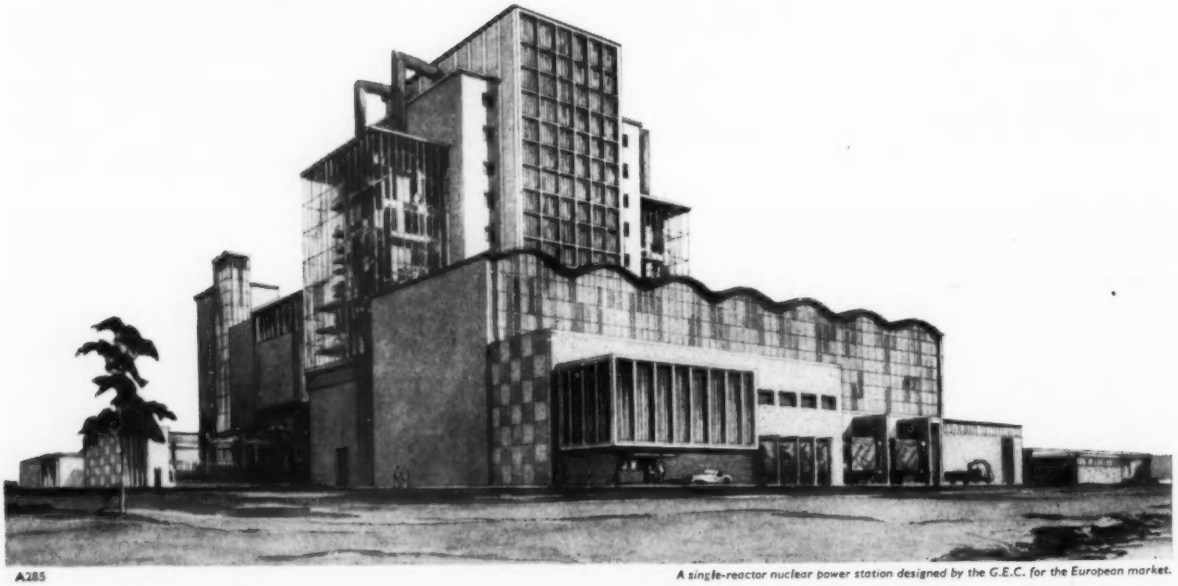
Nuclear power stations with electrical outputs ranging from 40-400 MW per reactor can be designed and built by the G.E.C. in any part of the world. The reactors, which are based on the well-established Calder Hall design, have been made possible by intensive research and development work at the Erith headquarters of the G.E.C. Atomic Energy Division.

G.E.C. ATOMIC ENERGY DIVISION



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A single-reactor nuclear power station designed by the G.E.C. for the European market.

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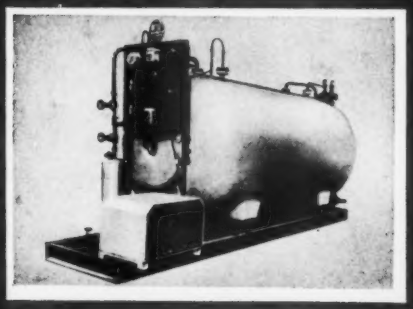

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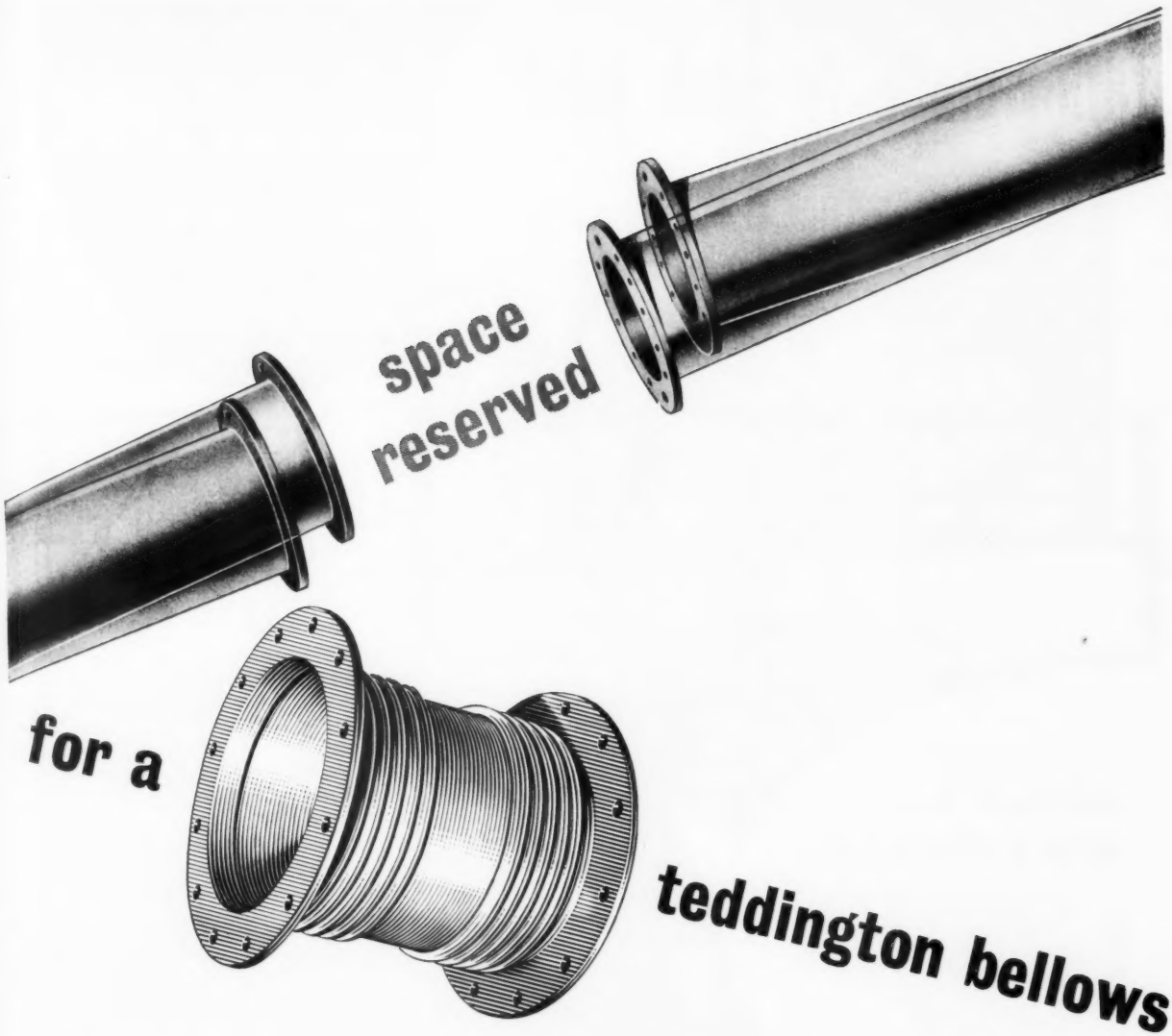

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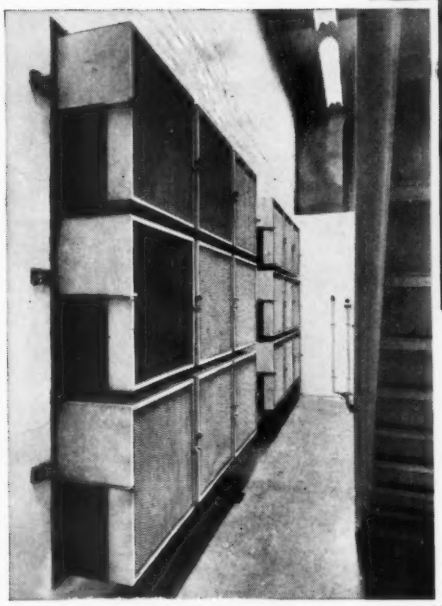
Vokes at Harwell



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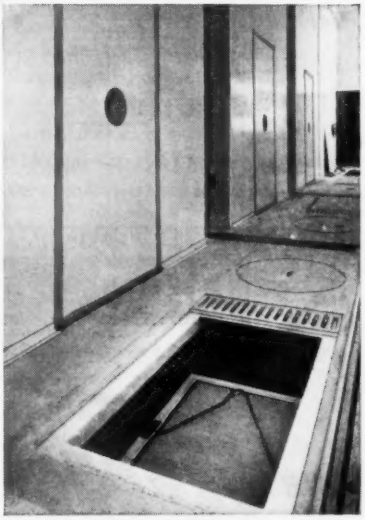
A Vokes 55 'Absolute' under-floor cell filter in the operating area. ▼



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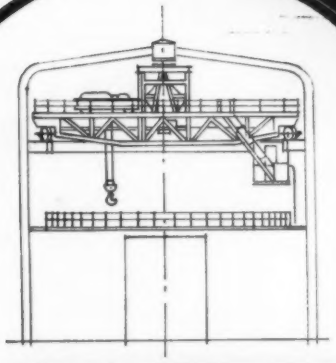
In the Atomic field



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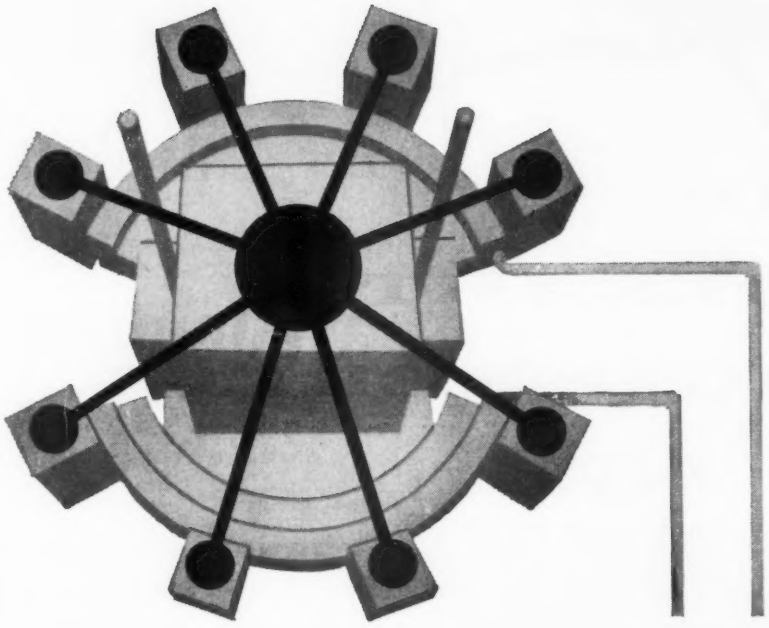
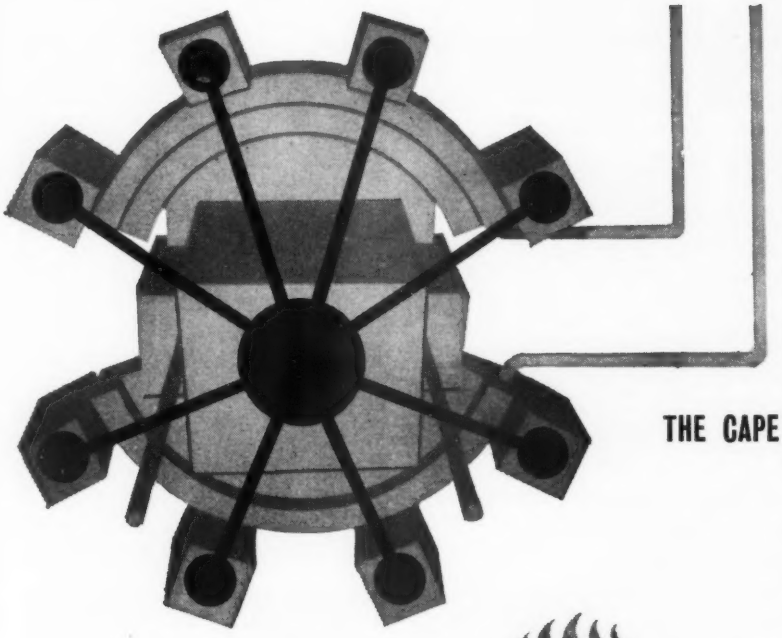


BERKELEY—a challenge to insulation



The heat developed by the twin reactors of the new Berkeley atomic power station poses problems of thermal insulation which will require new techniques in their solution. Confining and controlling such intense yet precious thermal energy constitutes a challenge—a test worthy of the knowledge and skill acquired in 65 years' experience of thermal insulation manufacture by The Cape Asbestos Company, to whom the contract has been entrusted.

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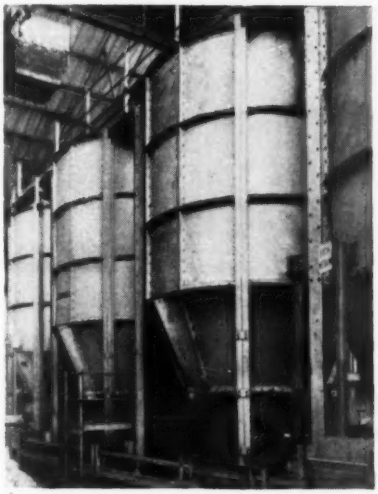

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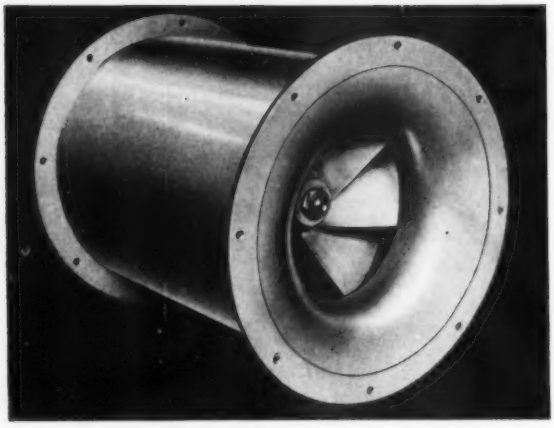

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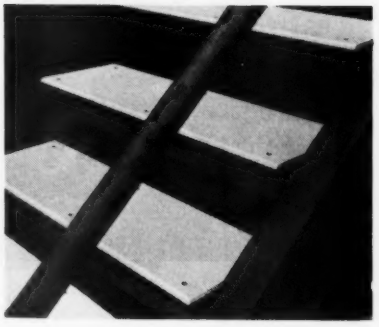
One of the many invaluable uses to which 'Corvic' is put is in the manufacture of safety treads for stairs. Factory stairs at the Ford Motor Co. Ltd., have Altro safety treads made from I.C.I. 'Corvic' by Welwyn Plastics (1955) Ltd. for the Adamite Co. Ltd.



'CORVIC'

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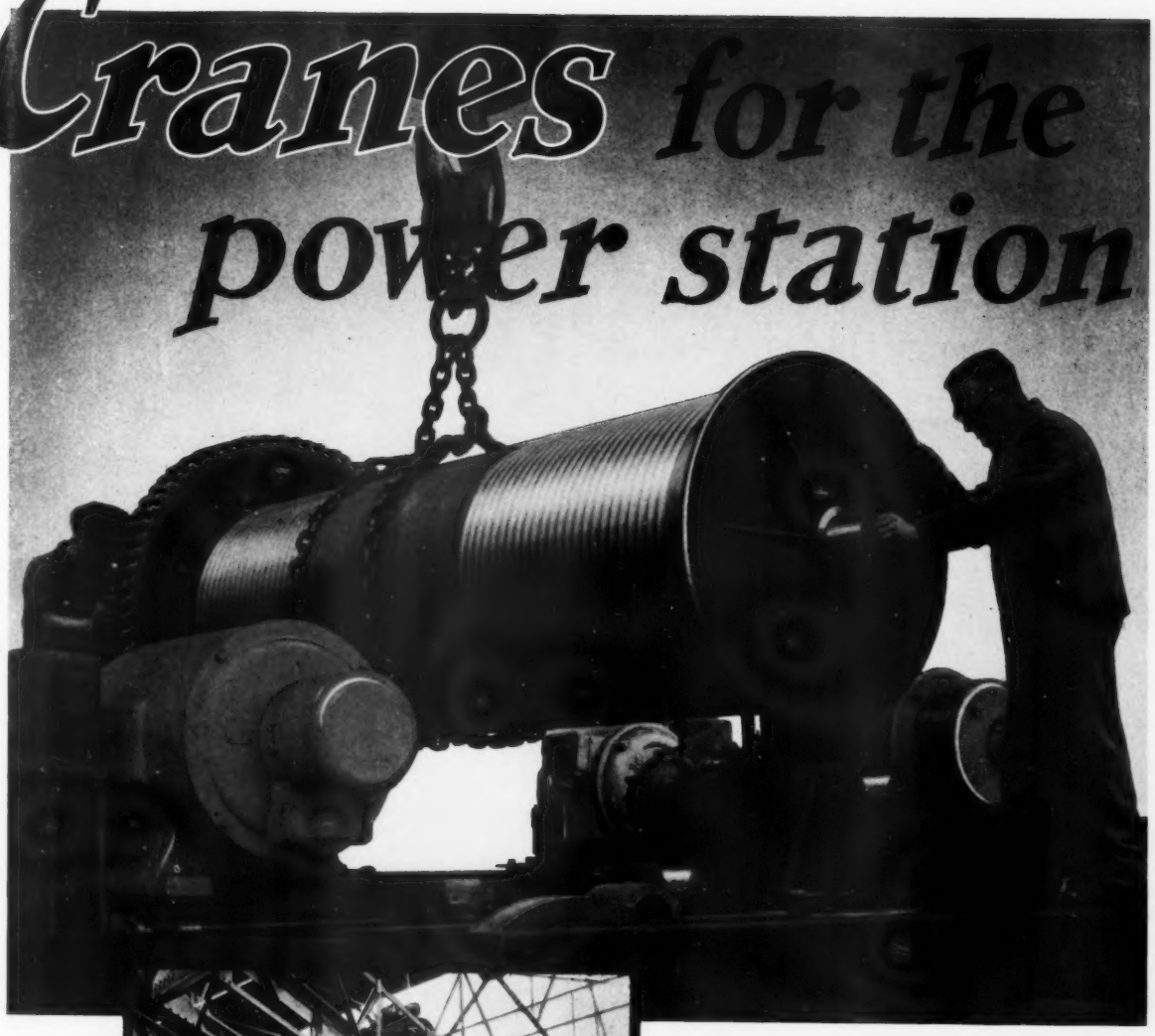
Cranes for the power station



THE massive rope drum for a 110-ton Morris crane is here shown being lowered on to the crab frame. Behind the drum is the crab traversing gear and the auxiliary lifting gear which in this instance is for a capacity of 10 tons. The crane was despatched to a power station in India—one more to the long list of Morris cranes already giving reliable service in power stations all over the world.

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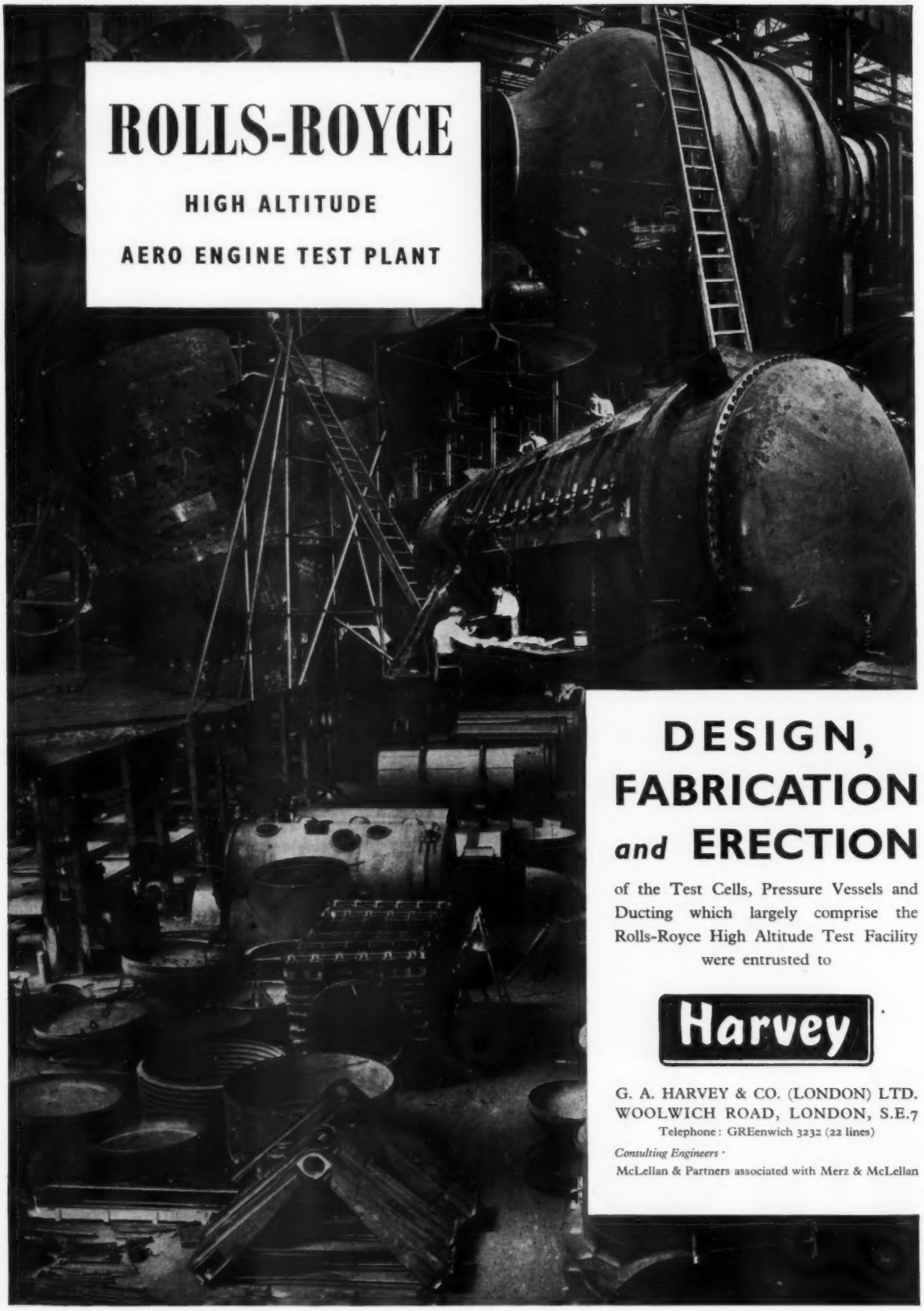

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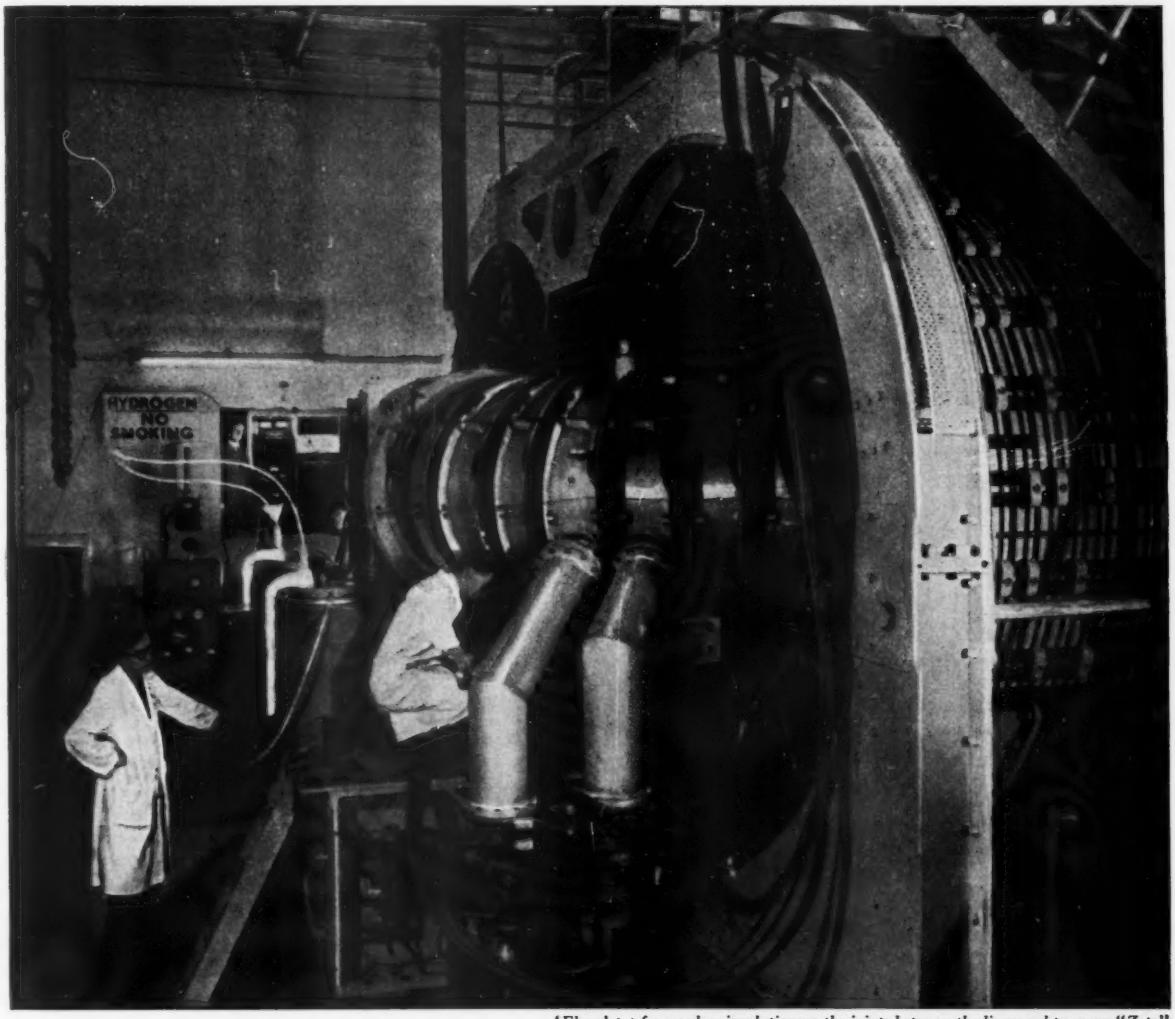

'Fluon' p.t.f.e. used as insulation on the joints between the liner and torus on "Zeta" designed by United Kingdom Atomic Energy Authority Research Establishment.

'Fluon' p.t.f.e. was used in the construction of "Zeta"

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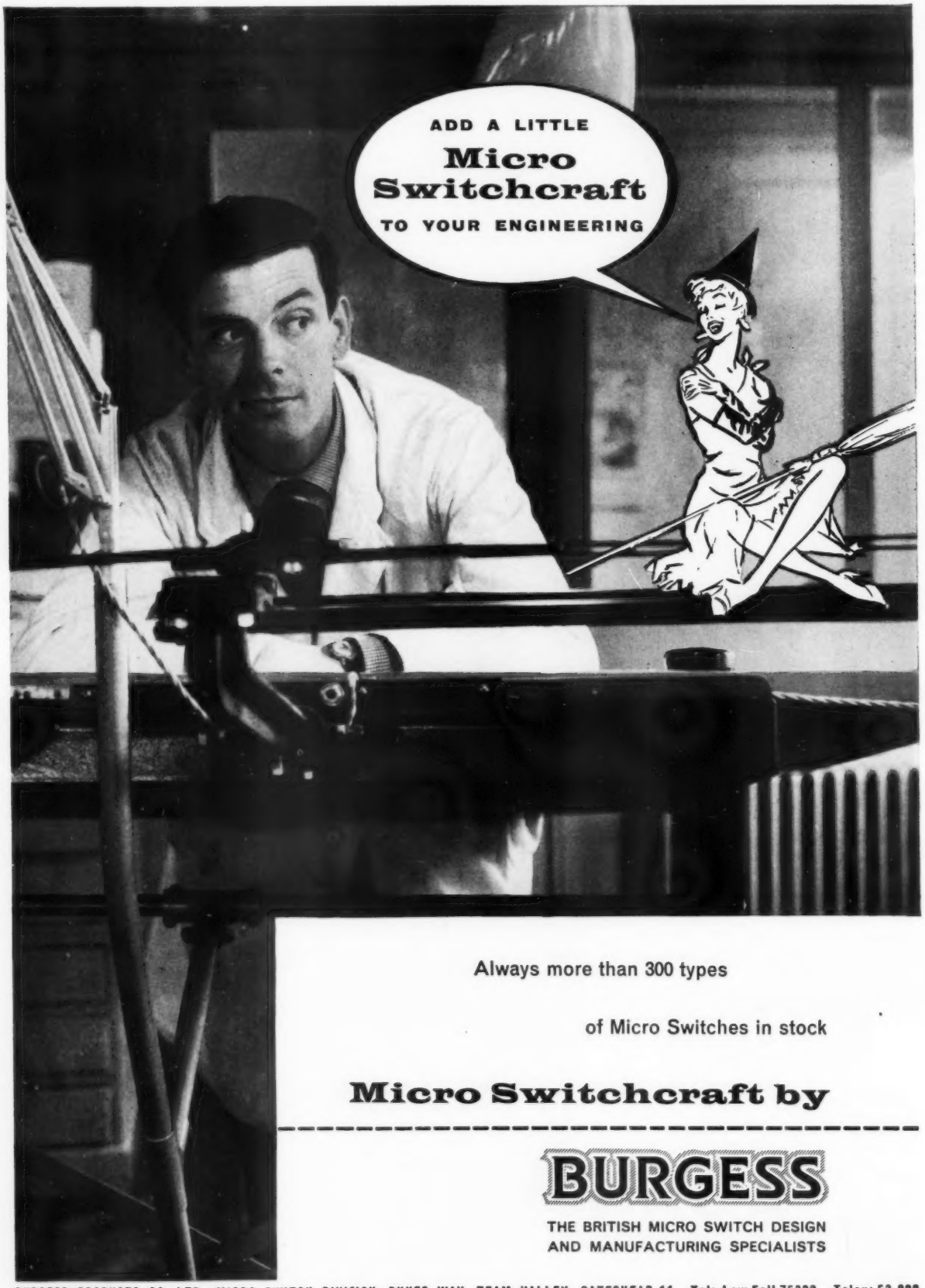

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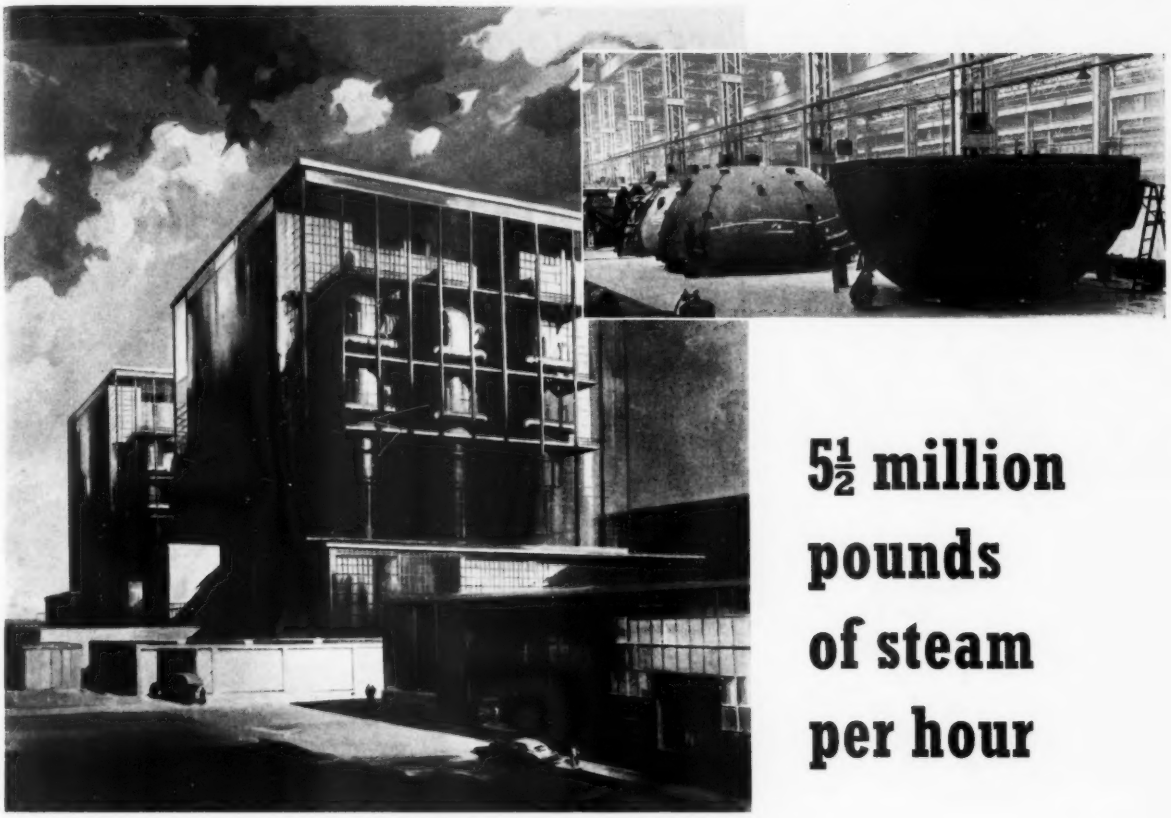

Illustrations by courtesy of Babcock & Wilcox Ltd.

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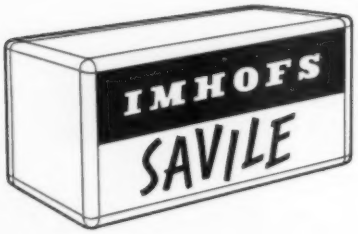

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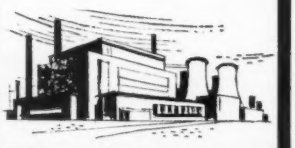

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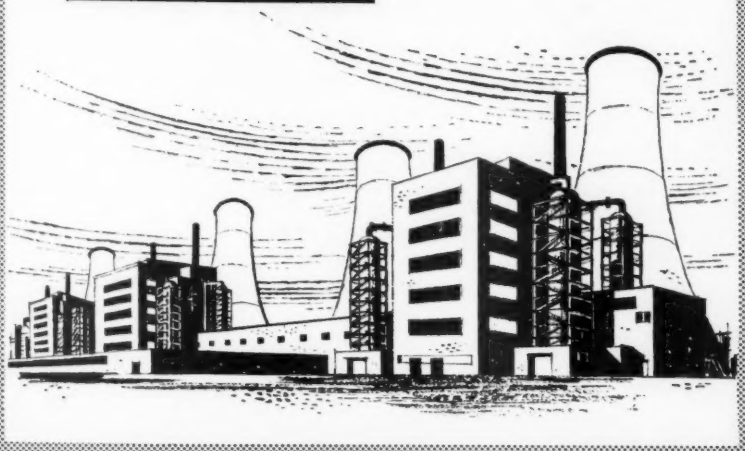

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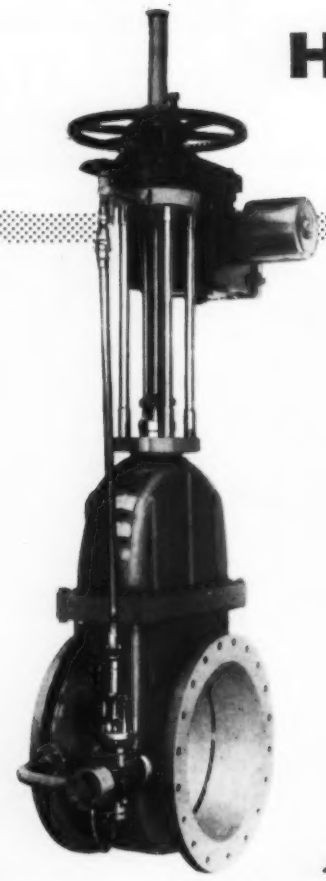

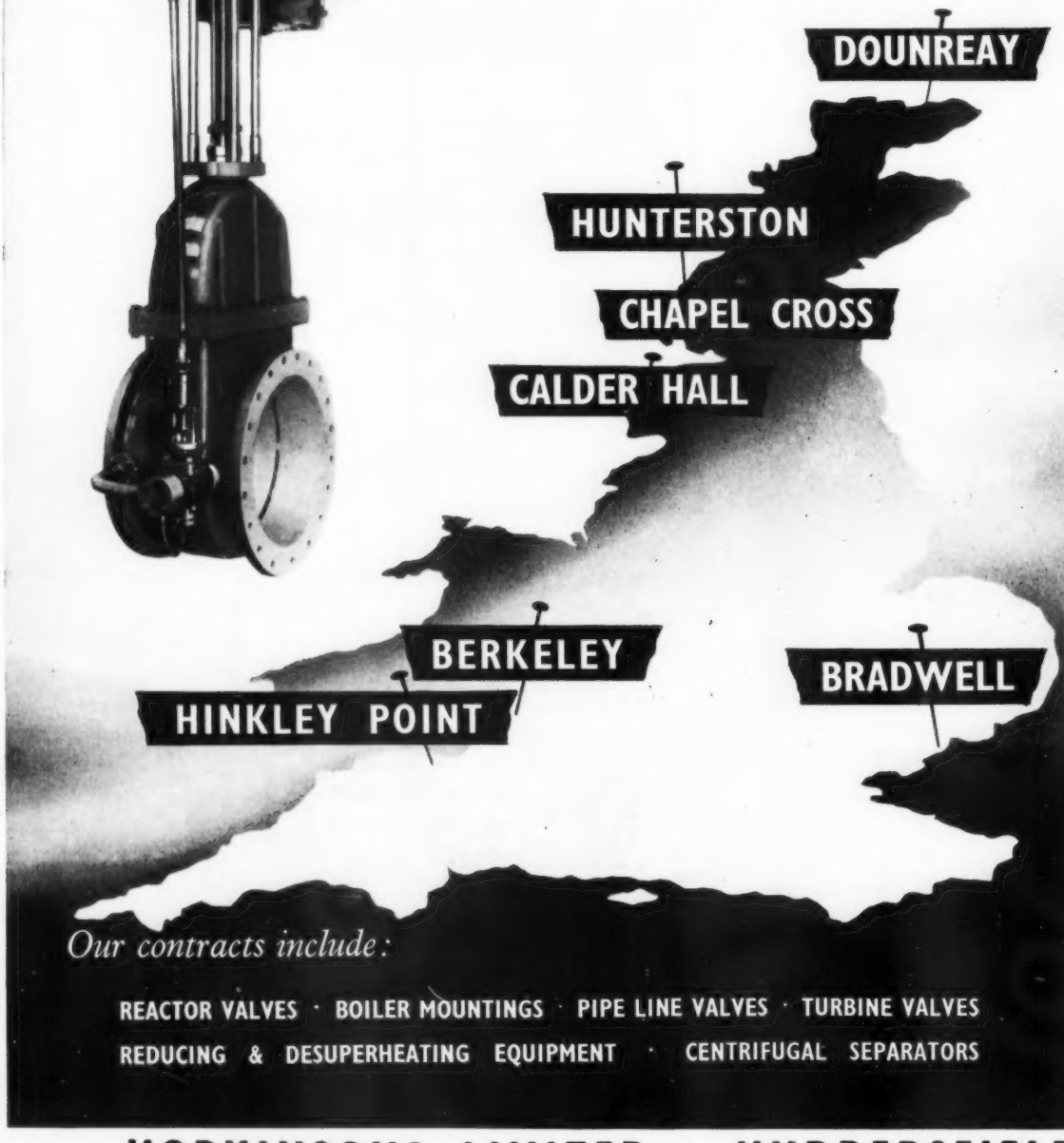

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II '59

G·A·M·E*

This is one of the magnetic memory drums used in G.A.M.E, the Sunvic data handling computer for analysing information from scintillation counters used to detect reactor fuel cartridge leaks.

The drum can memorise the previous 48 counts from each of 400-600 channel groups so that the previous 24-hours readings are always available. It also stores individual channel group reference levels and differential limits; each reading can thus be assessed arithmetically and warning given of *significant* variations in gas activity. The computer has completely self-checking circuitry with built-in fault finding equipment.

The covers of the memory drum have been removed and one bank of recording heads withdrawn. It revolves at approximately 150 r.p.m. and has a capacity of roughly 500,000 binary digits.

* **Gas Activity Monitoring Equipment—a patented system developed by Sunvic Controls, which is being supplied for C.E.G.B. use at Berkeley nuclear power station. For further information, please contact:**

SUNVIC CONTROLS LTD

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SC/75

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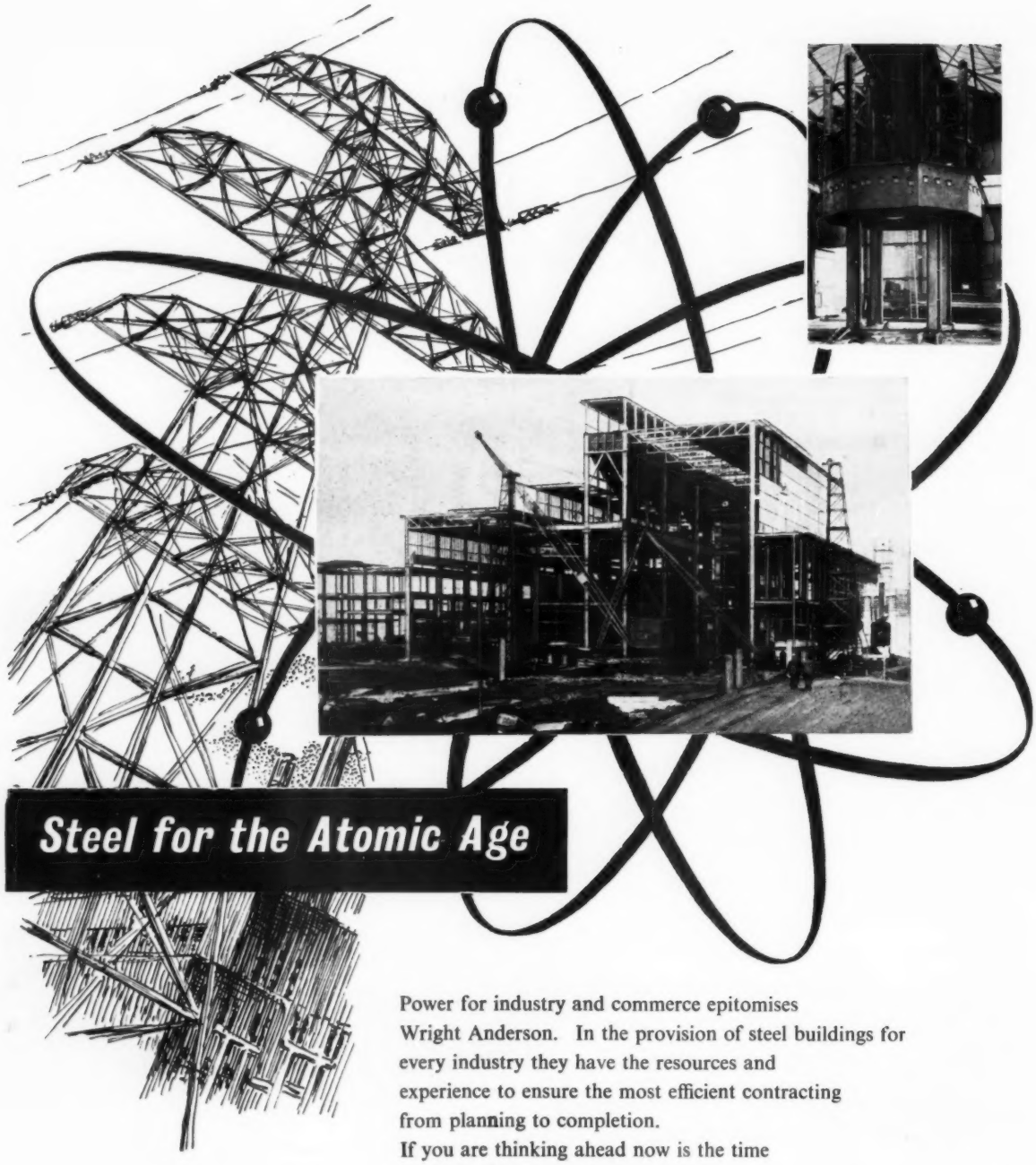

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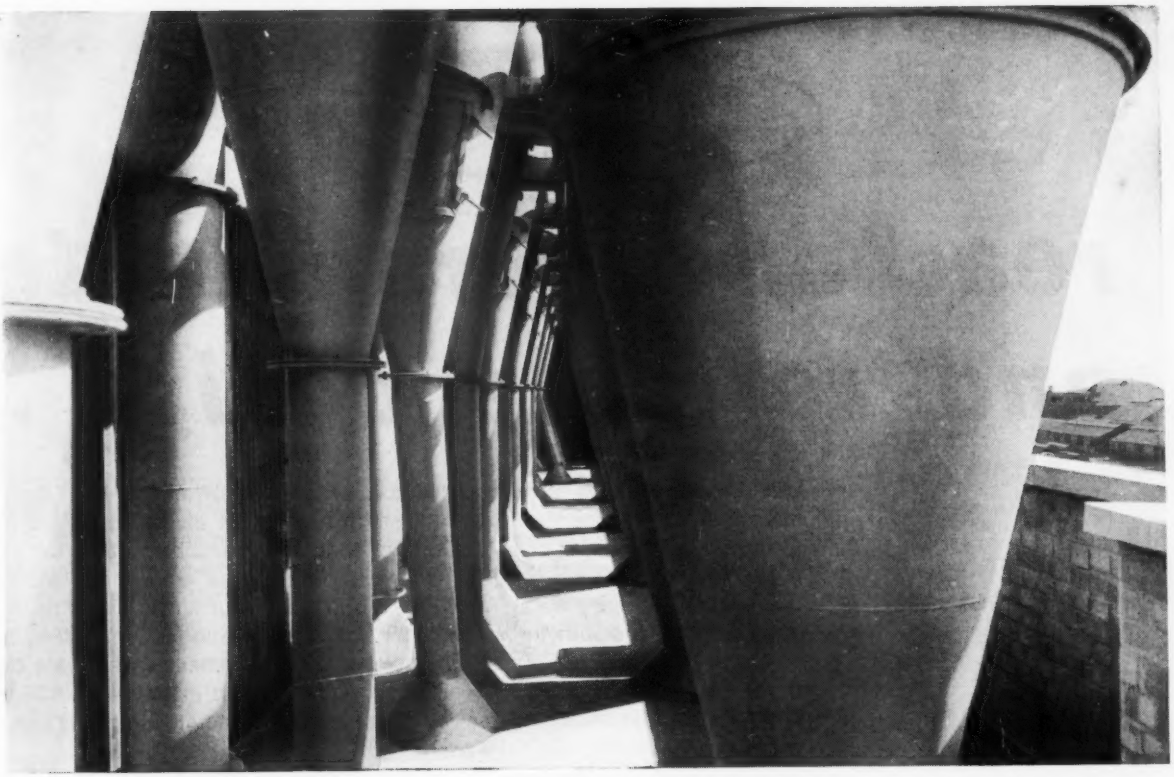
CONTRACTORS TO H.M. GOVERNMENT, CENTRAL ELECTRICITY AUTHORITY, NATIONAL COAL BOARD, ATOMIC ENERGY AUTHORITY AND CROWN AGENTS FOR OVERSEAS GOVERNMENTS AND ADMINISTRATIONS



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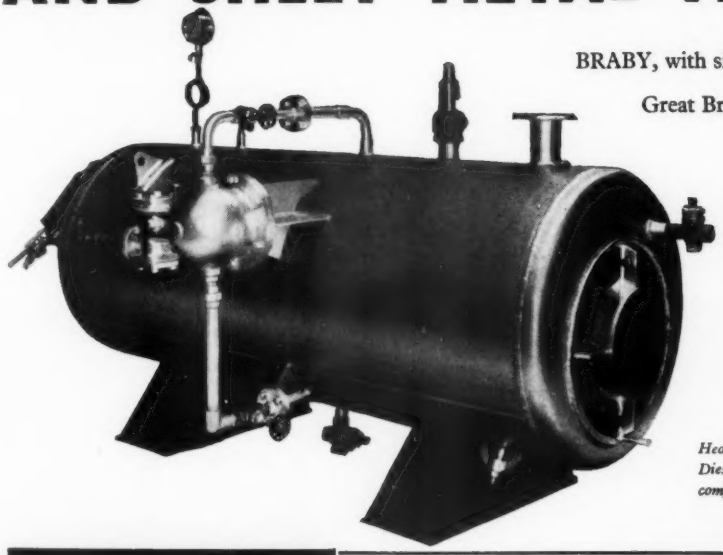

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AP 89

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acf

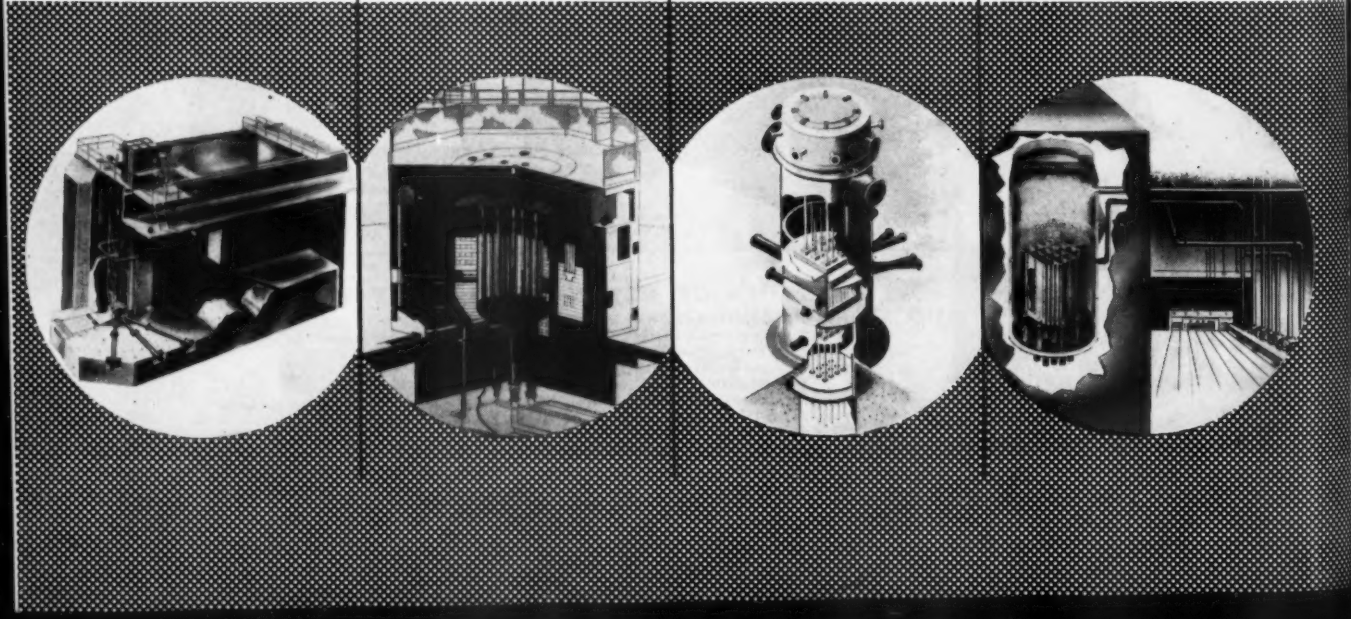
reactor diversification ba and reliable design ...

Unlike other builders of nuclear reactors who specialize in specific types — ACF has achieved prominence through diversification. This diversification is a tribute to the range and depth of our scientific, engineering and manufacturing skills. As a result of our field proven designs — today we offer a group of "standard reactors". The ACF Heavy Water Tank Type standard reactor is the direct result of the experience gained with the MIT reactor, the Italian National Committee reactor in Italy and other designs recently completed for government and private organizations. By combining the best features of each of these installations ACF is ready to offer a standard Heavy Water Tank Type research reactor with power levels ranging from 1000 KW to 10,000 KW.

Another standardized reactor is the ACF Light Water Tank Type—based on the best design features of 4 similar units now under construction in the U.S., Holland and Sweden with power outputs ranging from 10,000 KW to 30,000 KW. Used primarily for materials testing and engineering development, these units are further evidence of ACF's established pattern of reliability in reactor design and construction.

Two ACF Power Reactor Designs have recently been completed — one the Boiling Water Reactor Type and the other the Gas Cooled Type. The ACF approach to power reactor construction is based on the use of **proven** engineering and **sound** design to provide the customer with the most economic solution of his problem with **existing** technology.

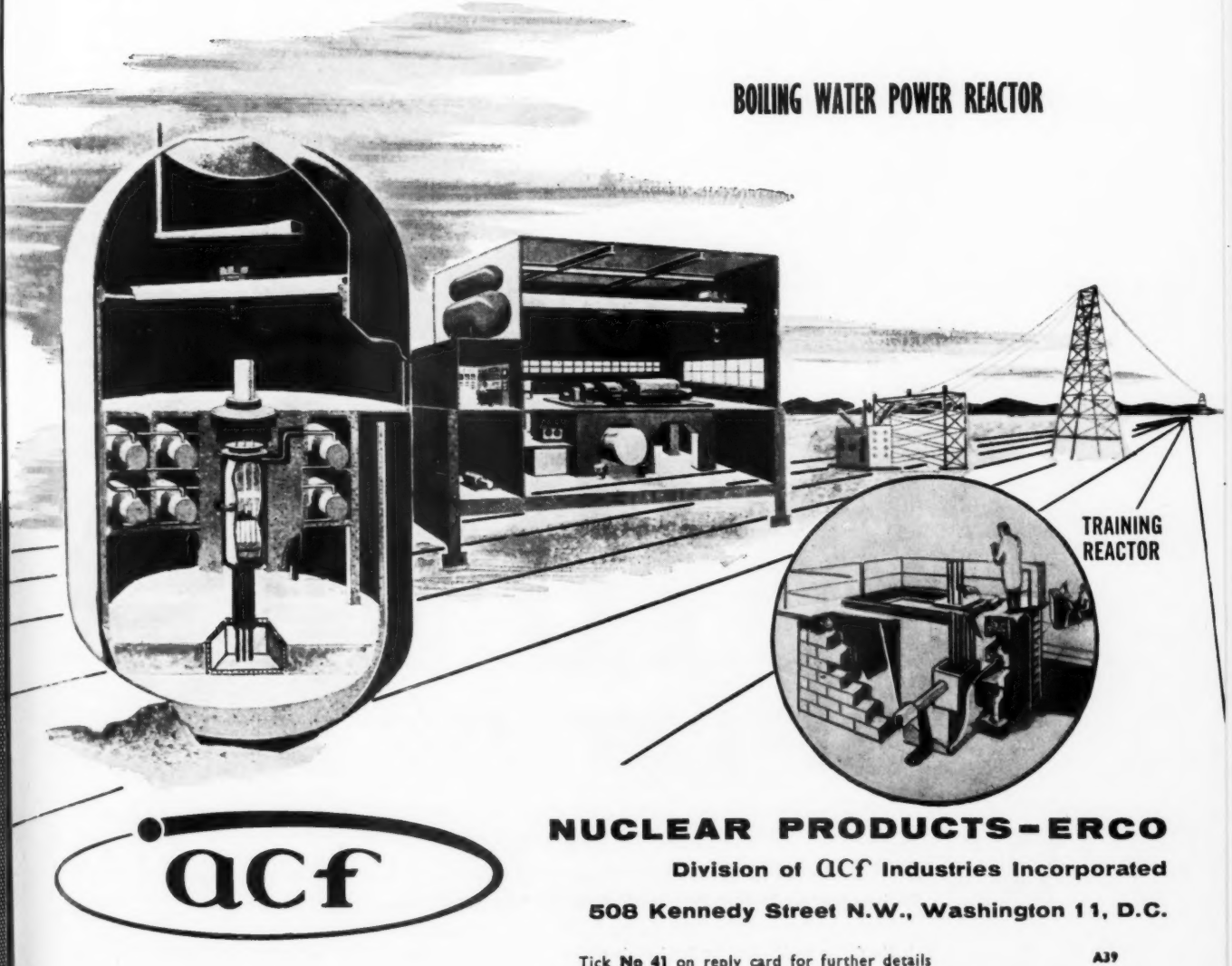
LIGHT WATER POOL TYPE | HEAVY WATER TANK TYPE | LIGHT WATER TANK TYPE | PROCESS HEAT



...based on experience

Other new design developments at ACF include the Process Heat Reactor and the complete line of Pool Training Reactors as announced recently.
Reactors from a 1 watt trainer to 150,000 TKW power unit have already been designed by ACF. matter what your requirements are in the area of nuclear reactors, the diversification, experienced personnel and proven designs found at ACF are your best assurance that we have a sound technical and economic approach to your problem. We are free at any time to undertake exploratory discussions.

Write to us for further information.



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Division of acf Industries Incorporated

508 Kennedy Street N.W., Washington 11, D.C.

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A39

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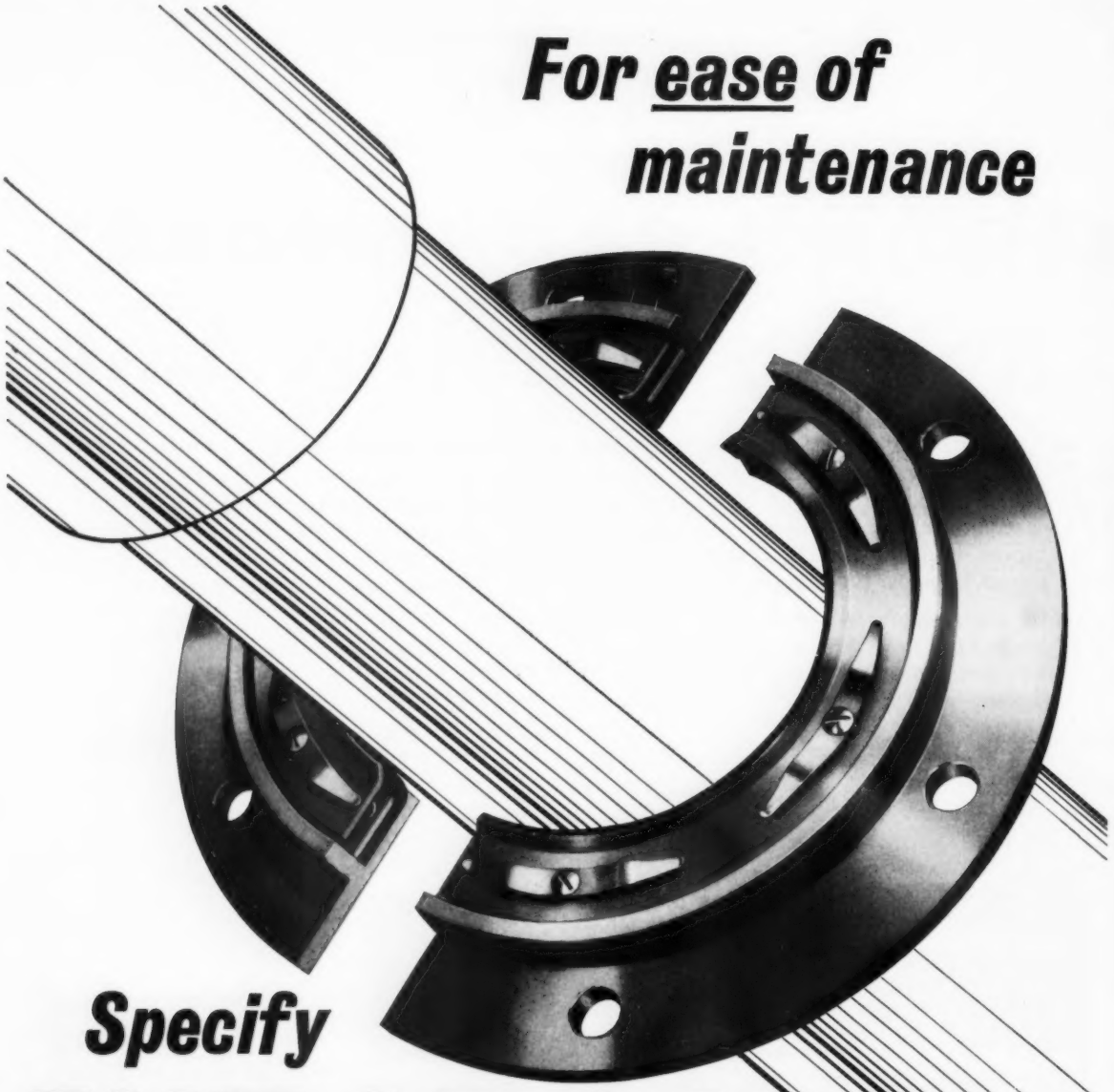

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Il est souvent difficile au client publicitaire d'indiquer dans un espace restreint tous les détails de ses produits. Dans le cas où vous désireriez de plus amples renseignements à ce sujet, veuillez pointer le numéro approprié sur la carte ci-contre et envoyer cette dernière à NUCLEAR POWER.

AUSKUNFTSDIENST FÜR LESER

Es ist oft schwierig für Inserenten alle technischen Einzelheiten über ihre Produkte in einem begrenzten Platz zu bringen. Sollten Sie noch weitere Auskünfte wünschen, streichen Sie einfach die bestimmten Nummern auf der nebenstehenden Karte an, und senden Sie sie an NUCLEAR POWER.

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Se hace a menudo difícil para los anunciantes dar en un espacio limitado todos los detalles técnicos sobre sus productos. Si desea ulterior información, marque los números apropiados en la tarjeta opuesta y mándela a NUCLEAR POWER.

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Часто бывает трудно рекламирующим лицам дать все технические подробности своей продукции в рекламе. Если Вам понадобятся добавочные сведения, то просто отметьте соответствующие номера на карточке на противоположной стороне и отправьте в NUCLEAR POWER.

讀者詢問服務

在廣告上以有限的地方來解釋一些專門技術及它們的功能的確是有受限制的困難。若你需要較詳細的情形就請將對貴的表格取一張下來將問下有關問的項目用笔勾一下即寄給子能工程总部可。

読者サービス

廣告紙面の関係上、製品の技術的細目は掲載しきれませんので詳しくは貴のカードの適當なナンバーに印をつけて係まで御投函して下さればお答へします。

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20	45	70	95	120	145	170	195
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At Bradwell, Essex, N.P.P.C. are building a new nuclear power station for the Central Electricity Generating Board, with a guaranteed output of 300 megawatts. This great enterprise is a commercial venture aiding Britain's economy and emphasising her world lead in the practical application of atomic power for peace.

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A Greater Britain through Nuclear Power

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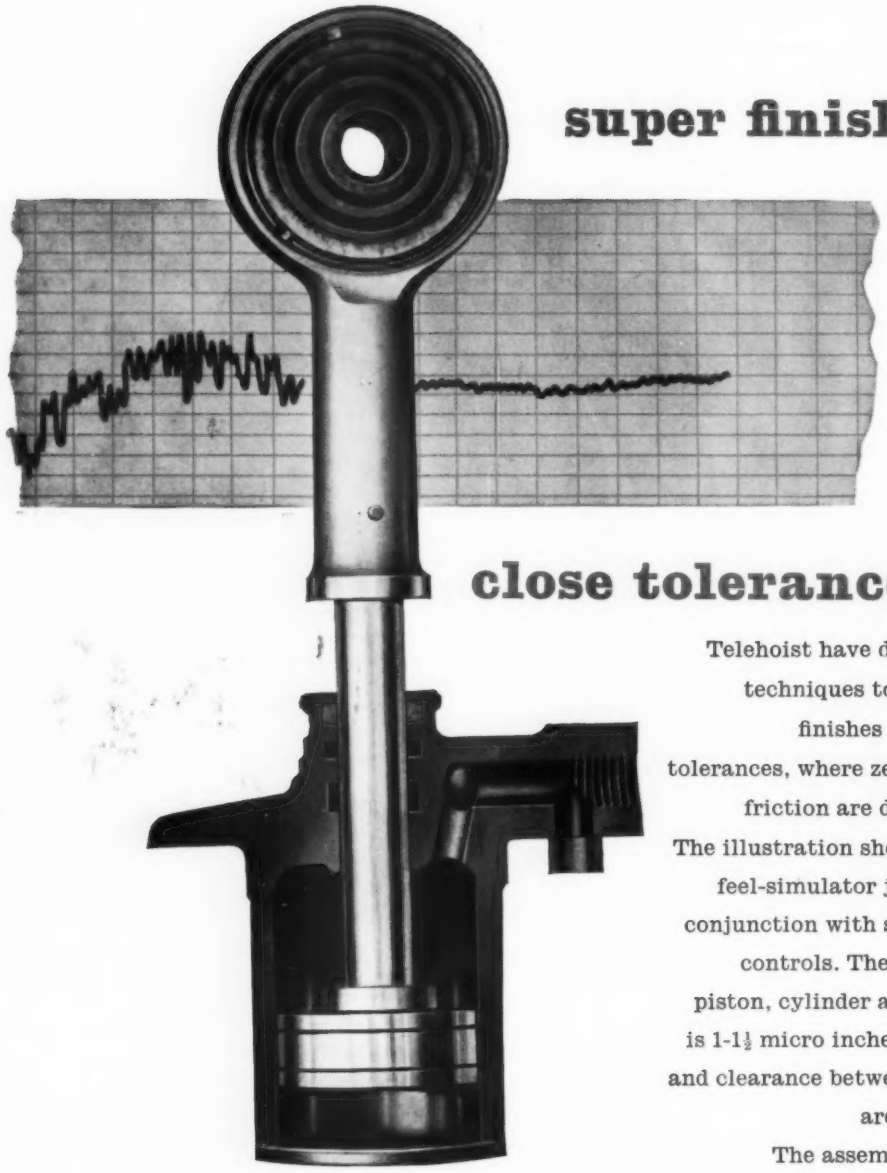

super finishing

close tolerances

Telehoist have developed production techniques to attain high surface finishes combined with close tolerances, where zero backlash and low friction are design fundamentals. The illustration shows an H. M. Hobson feel-simulator jack which is used in conjunction with servo operated flying controls. The surface finish of the piston, cylinder and spherical bearing is 1-1½ micro inches. The concentricity and clearance between working surfaces are within .0002 inches. The assembled units are tested at temperatures of – 40°C. and + 70°C.

If you have a production application demanding zero backlash and low friction characteristics we should be pleased to investigate and advise.

The illustration is shown by the courtesy of H. M. Hobson Limited.

Telehoist

are skilled in precision production engineering and super finishing

Telehoist Ltd Manor Road Cheltenham, *are an associate company of Wilmot Breeden Ltd*

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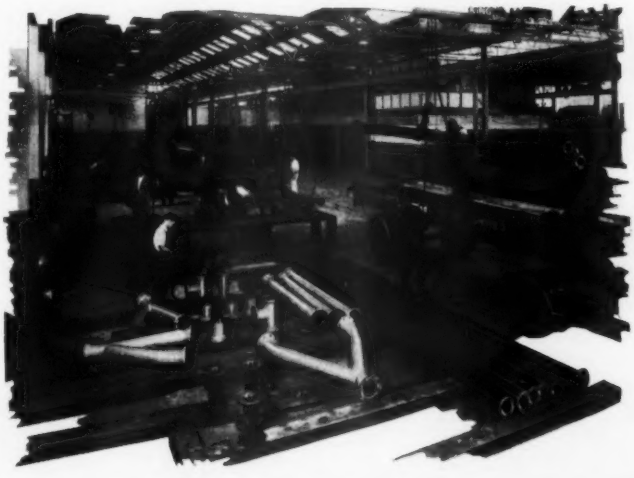
ABOVE: *Manipulated high pressure pipework in the assembly, inspection and despatch bays at Stewarts and Lloyds' Tollcross Works, Glasgow.*

BELOW: *New fabricating shop at Pudding Mill Lane, Marshgate Lane, Bow, E.15.*



Stewarts and Lloyds have a wealth of experience in the supply of manipulated pipework for all operating conditions. They have extensive research facilities and are able to design, manufacture and install pipework for every type of plant.

A large part of the Company's business comprises small orders for specials of all shapes and sizes.

To augment the efficient service already provided by our works in other parts of the country we have opened a new fabricating shop in London.

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THE WORLD FAMOUS

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known for their Design, Precision and Quality for more than 80 years.

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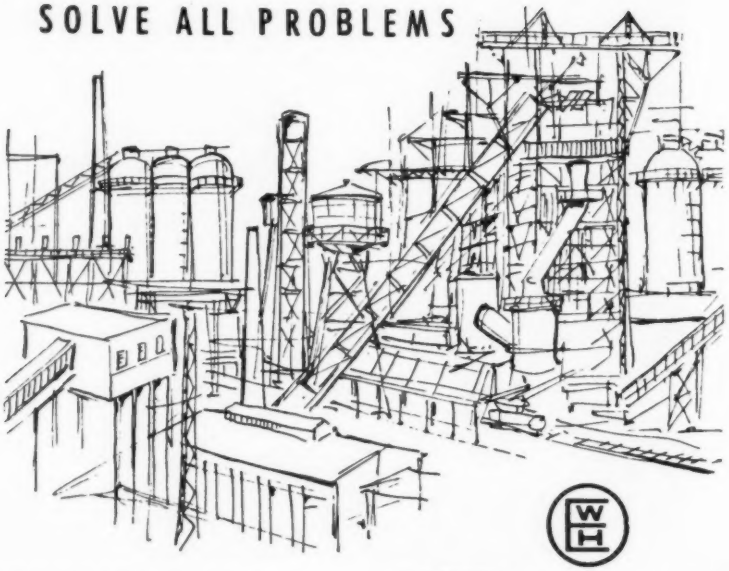

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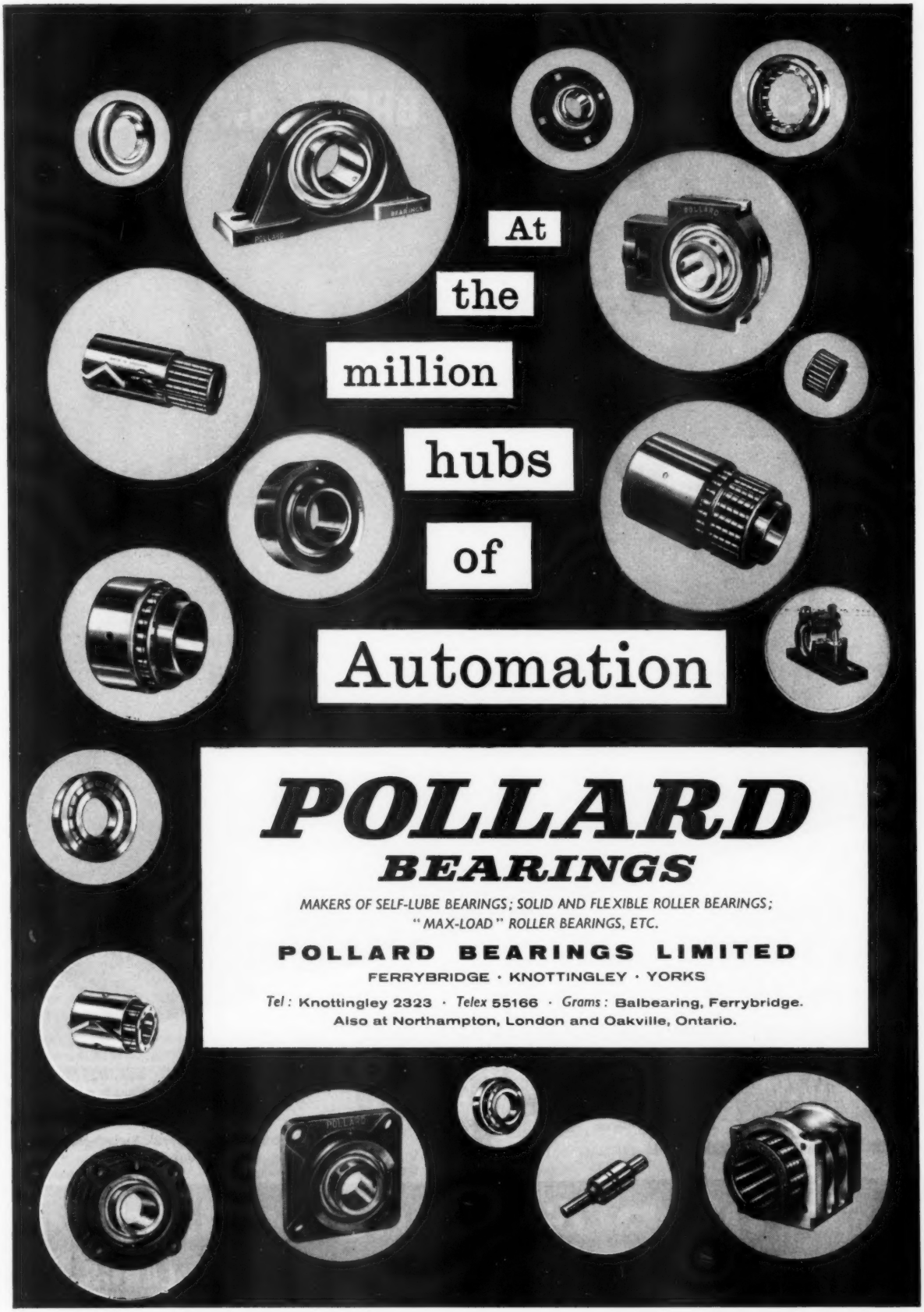

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CONSULTING ENGINEERS - MESSRS. KENNEDY & DONKIN

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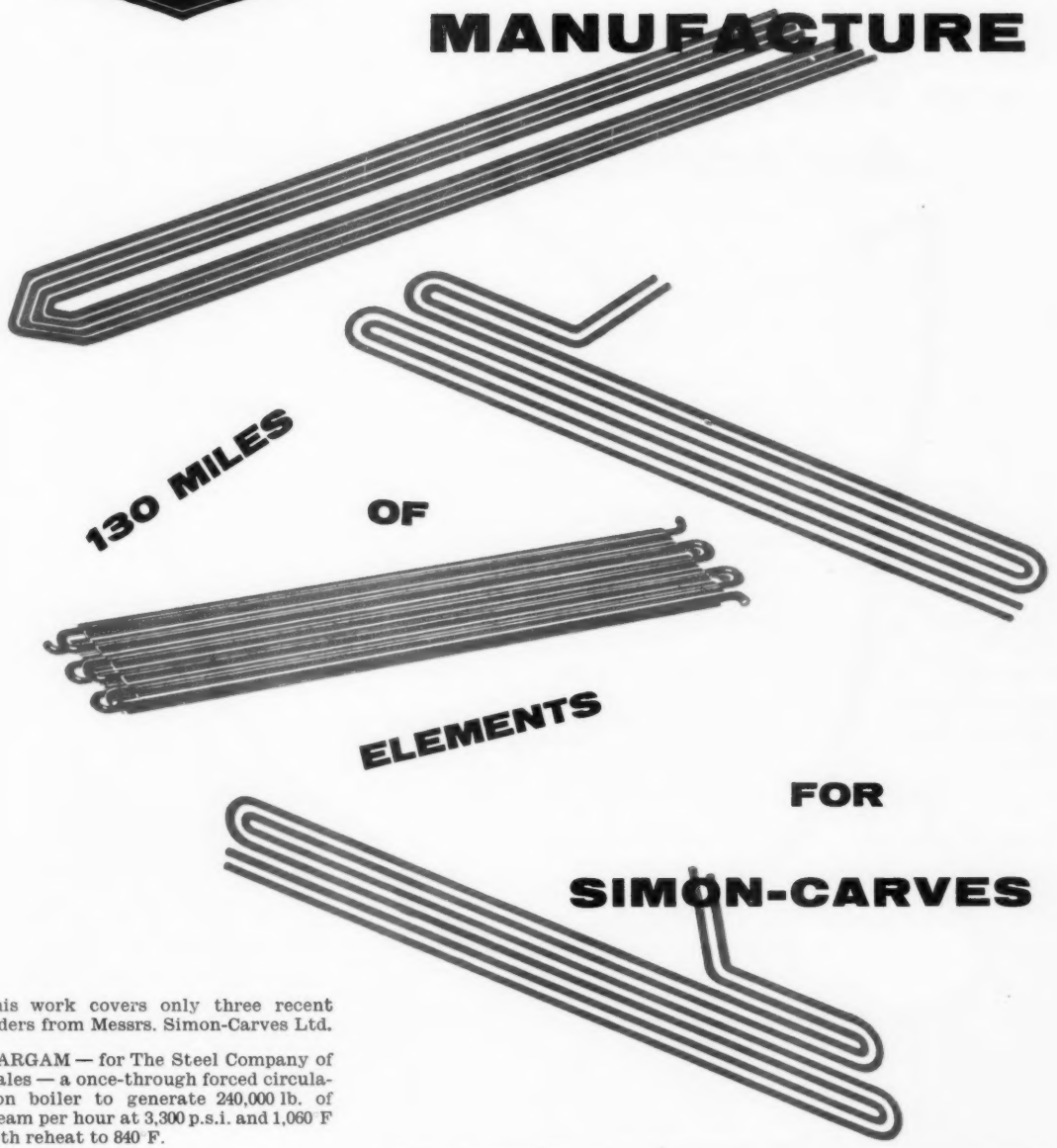

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ST. HELEN'S AUCKLAND, CO. DURHAM

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Westool also make: Coils & Coil Winding Machines, Transformers, Warner Electric Brakes & Clutches, Air Conditioners, etc. *and are Sole Selling Agents for the relays, sensing devices and micro-components manufactured by A. P. Besson and Partner.*

T1B94

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Series 500 and Series 700 A.C. Solenoids are available in Flame Proof enclosing cases, certified to Buxton standards.

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TURNERS
put Industry
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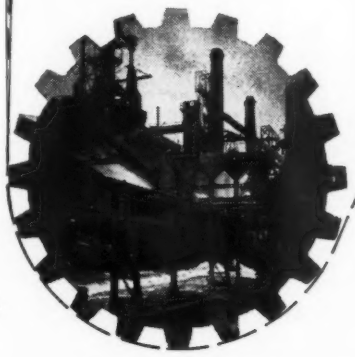
Public relations, staff recruitment and training, publicity and selling, are just a few of the fields in which industrial films by Turners have proved themselves invaluable in making the wheels of industry turn more smoothly and more swiftly.



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You are invited to write for details.

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Publishers Column

Specialists

These days nearly everyone is a specialist in something or other and the Editor of NUCLEAR POWER has quite a job each month providing a diet of pet subjects at a specialized level, rationed so that each of all our many different kinds of reader is at least aware that his own particular interests are not being neglected. Now specialist articles tend to be very long indeed and many scientists believe it is quite impossible to say anything constructive in less than 10,000 words. This is quite untrue and even a few hundred words—if they are the right ones—can be really useful. Of course the complete account of their work must be written for the record but it is not the function of a magazine to publish these at length. If we did, it would upset the whole balance and only alienate large sections of our readership.

It is almost certainly true that all significant advances in nuclear science and technology originate in specialist work but it is often some considerable time before the facts become available to those to whom they are most useful. We have felt for some time that we'd be doing a useful job if we could publish some of this work in a brief, concise manner as soon as it was available and this month we are starting a new section called *Nuclear Technology* in which we intend to include short specialist articles on a variety of nuclear topics. In this way we hope to focus attention on some of the many developments taking place which could be of significance to the future of applied atomic energy. This section is open to all and if you feel you could contribute to it the Editor will be glad to hear from you.

With our *Nuclear Technology* section NUCLEAR POWER takes another step forward which will accelerate even more its rapidly growing circulation and influence.

Looking to the future...

The world is making rapid scientific and technological progress but man's thirst for knowledge is insatiable. New methods of power are being developed and we have entered the nuclear age in the hope that these discoveries will help to secure a higher standard of living for all of us. But the need for fuel economy remains; that is why more and more industrial concerns are turning to Kenyon Planned Heat Insulation.

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TI4

Not so cheap

SIR: In his *Cross-Section* last month Gracchus, referring to the Italian SENN contract awarded to International General Electric, talks about the 'very much lower capital investment in a Dresden-type station.' In your report of the contract on p 526 however, you give the total cost for the 150MW station as £M22-23.

Now if my arithmetic is correct this is about £150 per kilowatt sent out and that is not particularly low. It would be interesting to know what the lowest British tender was.

Northampton J. PETTIFER

▶ *It certainly could be interesting! Capital costs of British-type stations for relatively small outputs such as the Project ENSI are not easy to obtain. For the very large twin reactor stations we are now planning for the UK (2 reactors, 600-800MW net) capital costs are estimated at £100-110 per kW (J. C. Duckworth, Geneva). For smaller stations the figure rises considerably. Some figures were produced at the Sydney symposium in June. For example, R. D. Vaughan of the Nuclear Power Plant Co gave about £130/kW for a 150MW station while A. L. Shaw of the AEI-John Thompson Nuclear Energy Co put a figure of about £145 per kW for a 150MW station built in Australia. Possibly the situation will become clearer when the result of the competition for the Japan Atomic Energy Company's station becomes known.* *Ed.*

Splitting the infinitive

SIR: One of the most closely guarded secrets of the era can now be told; how an anonymous group of grammarians, working in secrecy in a remote section of the country, have finally succeeded in splitting the infinitive.

The so-called 'Bronx-Project' got under way in 1943 with the installation of a huge infinitron specially constructed for the job by Cal Tech philologists. Though the exact details are still withheld for reasons of security, it is possible to describe the general process.

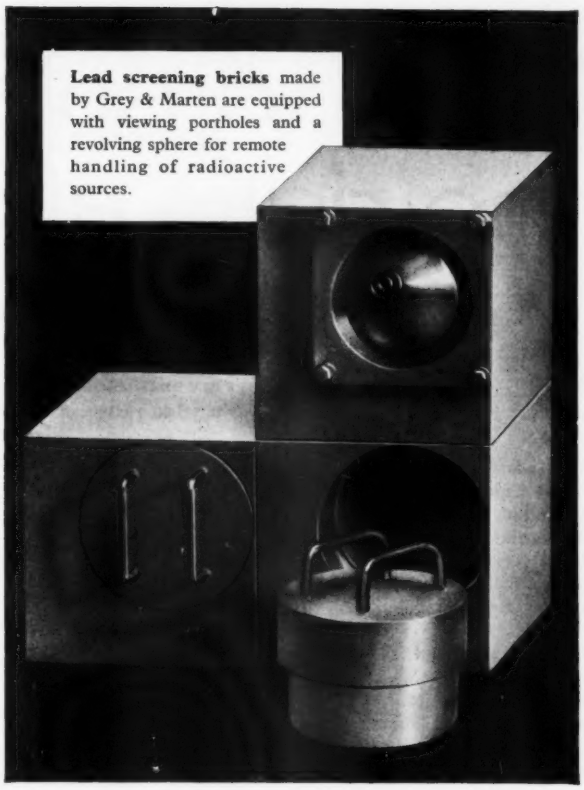
From a stockpile of fissionable gerunds, encased in leaden clichés to prevent radioactivity, a suitable subject is withdrawn and placed in the infinitron together with a small amount of syntax. All this material must be handled with great care as the slightest slip may lead to a painful solecism. Once inside the apparatus, the gerund is whirled about at a great speed, meanwhile being bombarded by small particles. A man with a Gender Counter stands always ready to warn the others if the Alpha-Betical rays are released in such high quantities as to render the scientist neuter.

The effect of the bombardment is to dissociate the whirling parts of speech from one another until at length an infinitive splits off from its gerund and is ejected from the machine. It is picked up gingerly with a pair of hanging clauses and plunged in a path of pleonasm. When it cools, it is ready for use.

The question is often asked: Can other countries

continued on p A53

Tick No 53 on reply card for further details



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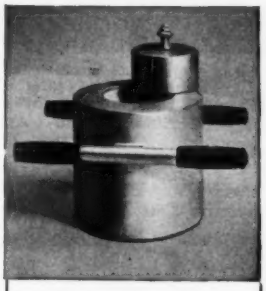

Storage pot typical of those used in standard safes not already fitted with lead protection, affords economical storage for radio-active material.

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How to select the right alloy

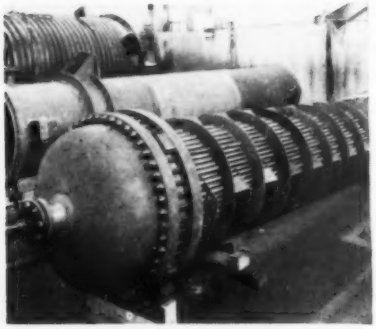
TO RESIST CORROSION

Many Wiggin wrought nickel alloys are outstanding because of their resistance to corrosion by a wide range of media.

Chlorination vessels of Monel used in the production of selective weed killers. Fisons Pest Control Limited.

Atmospheric Corrosion: INDOORS most high-nickel alloys are immune. In industrial sulphurous atmospheres Inconel is superior. OUTDOORS the rate of attack is low. Inconel remains bright in most atmospheres. Even where Monel tarnishes, there is no destructive corrosion.

Fresh and Salt Water: When water high in salts and dissolved gases is handled, Inconel is the preferred material. In salt water, Monel is generally preferred in submerged exposure and Inconel in exposure to marine atmospheres. Monel is the ideal material for propeller shafts, fastenings, valves and pump parts handling salt water.



Heat exchanger for chemical processing with tubes of Low-carbon A T Nickel welded to a nickel-clad steel tube plate. The dished head is also of nickel. Bertrams Limited.

Neutral and Alkaline Salts: Nickel resists this type of attack while Monel is widely used in salt processing. Inconel is especially suitable for equipment handling food and refrigerating brines since it resists pitting.

Acid Salts: Generally Monel is superior to nickel and Inconel with acid salts such as zinc chloride, ammonium sulphate and aluminium sulphate. Inconel is one of the few materials available for use in contact with hot, strong solutions of magnesium chloride and is superior for resisting oxidizing acid salts.

Oxidizing Alkaline Salts: Hypochlorites are the only common alkaline salts corrosive to Monel, nickel and Inconel.

Mineral Acids: Monel is among the few mechanically strong materials which resist corrosion by dilute hydrochloric and sulphuric acids. It is resistant to air-free hydrofluoric acids of all concentrations and at all temperatures including boiling. Monel is used in sulphonation, pickling and hydrofluoric acid alkylation. Nickel is useful in chlorination equipment.

Oxidizing Acids: Such as nitric in concentrations over 20 per cent have little corrosive attack on Inconel.

Organic Acids and Compounds: Inconel resists this type of attack so well that it is widely used in food processing and pharmaceutical manufacture. Nickel is frequently chosen for food processing equipment because of its ability to protect purity. Monel is useful in resisting corrosion in the manufacture of fatty acids.

Alkalies: Alkalies such as caustic soda have practically no corrosive effect on nickel. In less severe applications Monel is often used. Inconel is chosen where alkaline sulphur compounds are handled.

Wet and Dry Gases: At atmospheric temperatures no dry gas is actively corrosive to nickel or to Inconel. Nickel is one of the most useful materials for handling chlorine, fluorine and bromine at temperatures up to about 540°C. and is free from corrosion by steam up to 425°C. Inconel is used for handling steam up to about 800°C. Above this temperature one or other of the Nimonic Series of Alloys is generally used.

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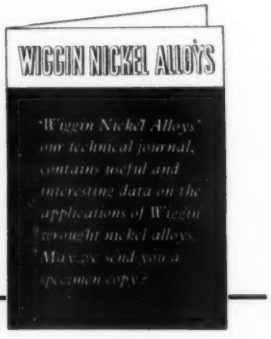
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TGA H/C8

SIR!

continued from p A51

likewise split the infinitive? I think we can safely answer, 'No.' Though it is true that Russia, for one is known to have large supplies of thesaurus hidden away behind the Plural Mountains, it is doubtful if the Russians possess the scientific technique. They have the infinitive but not the knowhow.

And that is something on which to congratulate our own brave pioneers in the field of grammatical research. Once it was thought that the infinitive could never be split—at least, not without terrible repercussions. We have shown that it is quite possible, given the necessary skill and courage, to unquestionably and without the slightest shadow of a doubt accomplish this modern miracle.

See how easy, once you know how?

Author's name withheld for reasons of security

▶ *We are now able to reveal that for some time* NUCLEAR POWER*'s research team have been working on the related problem of thermosemantic fission. If two words are brought near enough to each other sufficiently often, they can be made to fuse into one. For example, take the simple case of the two elementary words 'burn' and 'up.' These often appear in the hyphenated form 'burn-up.' This, however, is only a molecular bond and of no interest to this study. The first step in fusion is the form 'burnup,' achieved here for the first time several months ago. This reaction requires a great deal of energy as there is a lot of resistance to be overcome and marks a distinct step forward by our team.*

However, this is only a transitory stage as no particles are emitted and the Fowler barrier has not been overcome—complete fusion means that temperatures will have to be raised even higher. By improvements to our machine, COED*—which has had no modification since 1934—we hope to achieve the reaction*

$$\text{burnup} \xrightarrow{(n,u)} \text{burp}$$

The economic significance of this development will need no emphasising, but unfortunately its widespread application may not be entirely peaceful. *Ed.*

NP in Sweden

SIR: During the past year you have sent NUCLEAR POWER to the Chamber each month. It has occupied a prominent place on our library table and proved a valuable source of fact and opinion for the monthly reports published in our *Economic Review*. In recent months NUCLEAR POWER has been glanced at and read with particular attention, in view of the British-Swedish Nuclear Energy Meeting which was arranged in Stockholm by the Chamber and which was addressed by Sir Claude Gibb and Mr H. Brynielsson, the managing director of the Swedish Atomic Energy Company.

I should like to express appreciation of NUCLEAR POWER and hope that the Chamber may continue to have the pleasure of receiving it.

British-Swedish Chamber of Commerce in Sweden, Stockholm N. PARSONS

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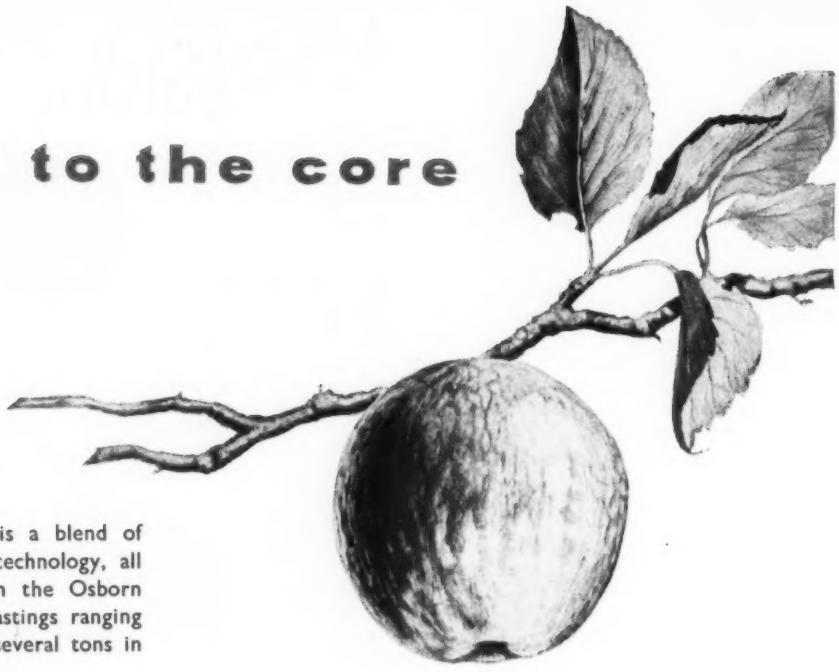
Sound to the core



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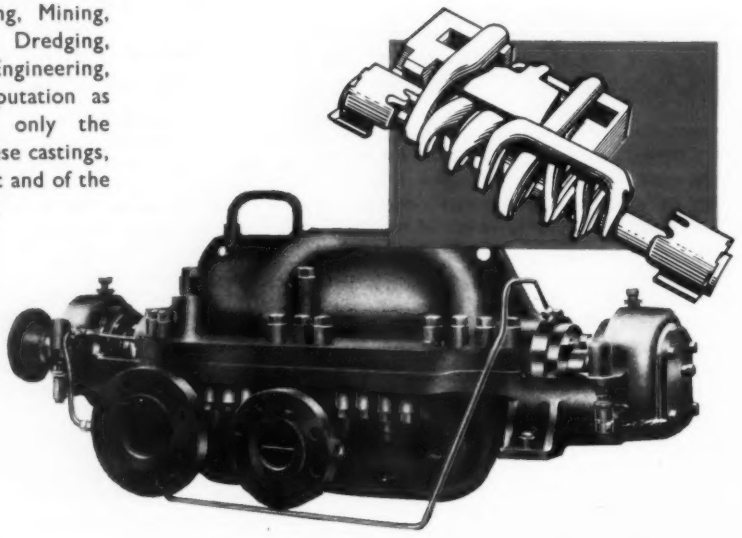

Osborn steel castings are used in this 6-cwt. *Hayward Tyler - Byron Jackson six stage 'Multiplex' pump.* Inset illustrates core used for casting the lower half of casing.

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Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING
DECEMBER 1958 VOLUME 3 NUMBER 32

Bone of Contention

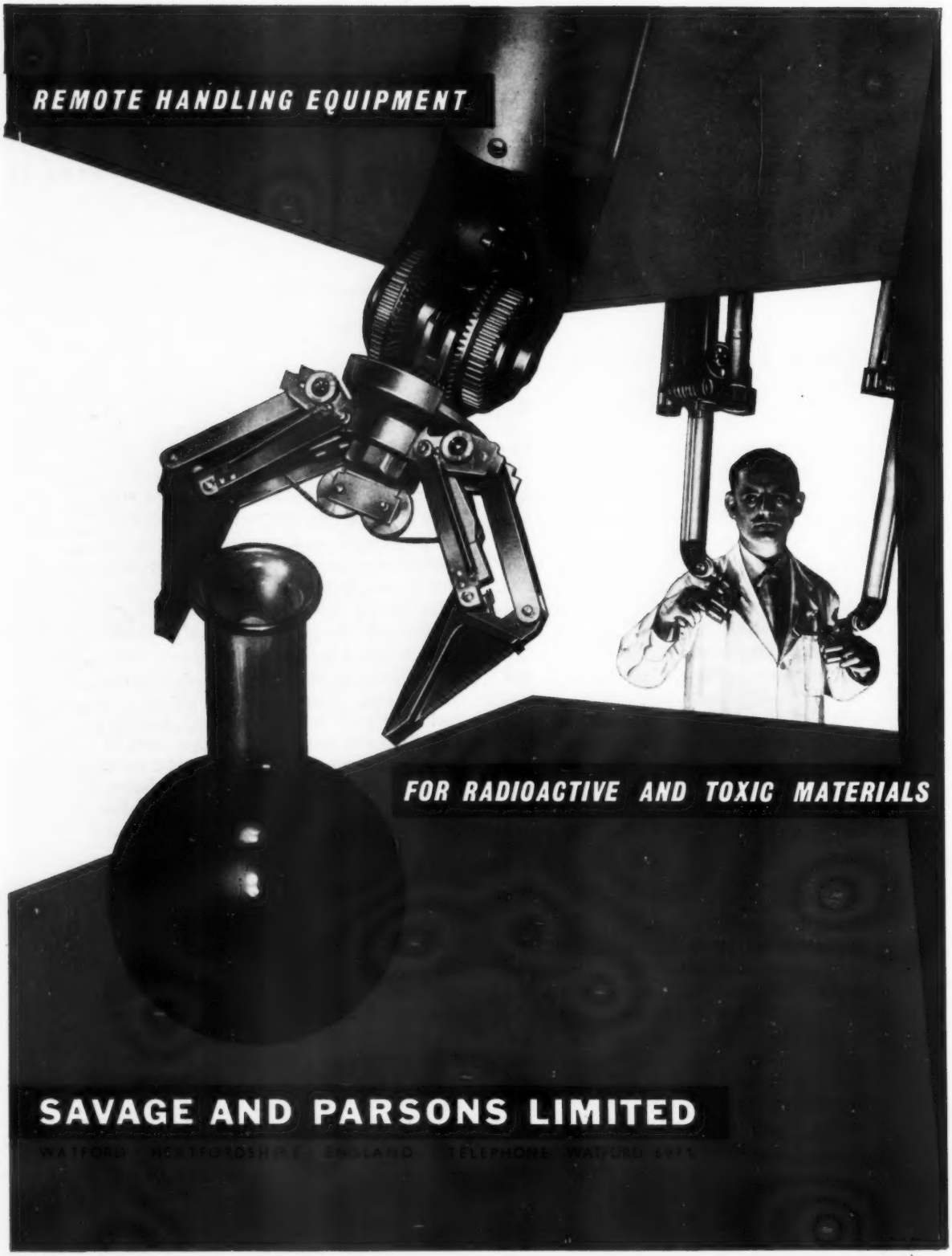
Atomic energy is really quite a controversial subject although one would never think so to judge from the numerous carefully-written articles from official and industrial sources. Hints of disagreement sometimes emerge at discussions following learned papers but on the whole the general impression is of a lot of people working away steadily in perfect amity on all subjects at all levels. The whole history of science and technology shows, however, that this is inconsistent and that somewhere there must be bones of contention at least as large and hard as those gnawed by successive generations of scientists from Aristotle onwards. Science, in fact, thrives on controversy and now that atomic energy is to a very large extent declassified there is no reason at all why arguments which have for years gone on in private should not be publicly aired. This is certainly done in other fields of engineering and undoubtedly provides a valuable stimulus to thought.

For these reasons we welcome in this issue the article by Mr K. L. Stretch who, as works manager at Calder Hall, was in a good position to assess the many problems involved in the building and operation of a large nuclear power station, and who, in his present position with the National Coal Board, is well equipped to see the nuclear power programme in relation to the wider one of energy resources. Mr Stretch pulls no punches and while we do not necessarily agree with all his points, many of them seem to warrant serious consideration and further thought.

In the UK we have achieved a very notable success in atomic energy on a rather narrow front by using a unique kind of collaboration between government and industry. But just because it has worked fairly well up till now, this does not mean that some other type of approach would necessarily have failed or that the system we have must be perpetuated as a permanent feature of our industrial scene. Indeed, there are signs that we may be approaching the point where some kind of change is desirable. There are, for example, the views that the AEA should begin to take a back seat and hand out more research and development work to industry, that industry should play a larger part in fuel production and reprocessing, that the CEGB should take a much bigger hand in actually designing power stations, that more use should be made of consulting engineers, that reactor groups should be given more encouragement to plan and build advanced reactors on their own initiative.

All these proposals are fraught with difficulties and dangers, are unlikely to find general acceptance, and are even mutually exclusive. But they are the sort of thing people talk about. Also they can only be discussed intelligently within the context of national security, public safety and the general economic policy. Nevertheless, there is discernible at the present time a certain lack of direction or loss of momentum in nuclear power and this impression the British papers at Geneva did nothing to dispel.

It would be too much to expect an actual programme for, say, the period 1965–70 since technical development is moving so fast, but the trouble is there doesn't even seem to be a policy. Perhaps there really is one: but if there is, it is apparently classified.


REMOTE HANDLING EQUIPMENT
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Worldview

the month in atomic energy

Export No 2; no decision yet

The tenders for a 150 MW gas-cooled graphite-moderated nuclear power station in Japan by three British consortia—the General Electric, English Electric and AEI-John Thompson groups—will be opened in Japan at the beginning of December. They were delivered last summer but have remained sealed while Japanese scientists familiarized themselves with the various design aspects of atomic power plants. To help them in this the Atomic Power company of Japan held discussions recently with delegations from the three British groups in a series of conferences and recorded the questions and answers on tape for study at leisure. Scientists, government officials and experts from the company are now running through the tapes and expect to be ready to open the tenders in December. Negotiations will then begin on points such as guarantees, credits and the proportion of the station which could be made in Japan and a contract is unlikely to be signed before next January or February. It is reported that one of the tenders—the English Electric group's—foresees the manufacture in Japan of at least half the contract and offers extended payments for the other half, with interest to vary directly as the Bank of England rate; also that the special strengthening against earthquakes would add 1 or 2 pc to cost and only a few weeks to construction time.

Chapelcross No 1 goes critical

The first of the four reactors at the Atomic Energy Authority's Chapelcross nuclear power station went critical on Nov 9. It is now working at low power and undergoing tests preparatory to getting up to its full rating of 45 MWe; sometime next year it will start feeding power into the National grid. The remaining three reactors are expected to go into operation at quarterly intervals and all four should be working by the end of next year. This news of the starting up of Britain's second nuclear power station comes two years after the first reactor at Calder Hall went in operation.

Three directors quit APC

Leon Bagrit, managing director of Elliott Brothers and Elliott Automation, has resigned from the Board of Atomic Power Constructions, in company with Dr Lawrence Ross, also a director of Elliott's, and Alan Mais, a director of Nuclear Civil Constructors. Alan Mais is also joint managing director of Trollope and Colls, which together with Holland & Hannen and Cubitts Ltd forms Nuclear Civil Constructors.

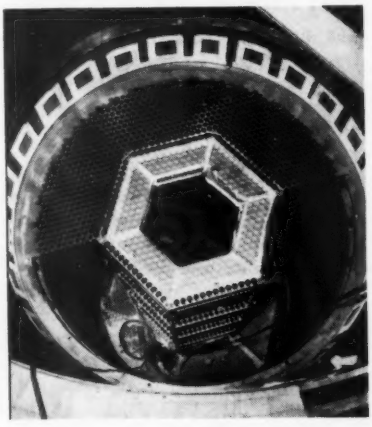
The firms making up APC, which was formed early in 1957 as the fifth of the UK nuclear consortia, are Richardsons Westgarth (turbo alternators, gas blowers etc), International Combustion (pressure vessels, heat exchangers etc), Crompton Parkinson (electrical equipment), and Fairey Aviation (fuel elements), besides Elliott Brothers (instruments) and Nuclear Civil Constructors (civil engineering). Elliott's now appear to have no direct link with APC and evidently want to take a more independent line in future.

Enquiry forced on Dungeness

The Minister of Power has decided to hold a public enquiry starting Dec 16 into the CEGB's proposal to build its fifth nuclear power station at Dungeness in Kent. Objections have been voiced to the plans for running transmission times from Dungeness to a substation at Lydd, and to a compulsory Purchase Order which has been made for land

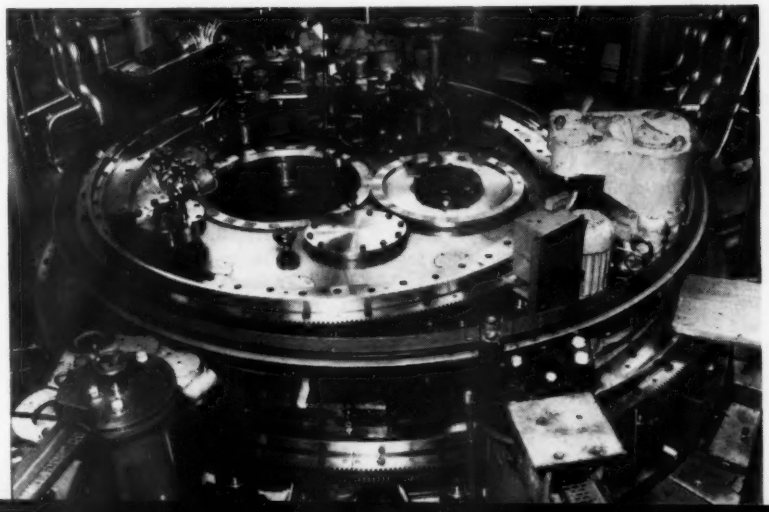
Final assembly at Dounreay

views of the fast breeder reactor



With the inner breeder blanket of natural-U rods in place [top left] the core skirt which contains the enriched fuel is lowered into the centre [top right].

Below is the complicated arrangement of rotating eccentric shields giving access to any fuel element. Initial trials of the reactor are due shortly



at the projected site of the power station.

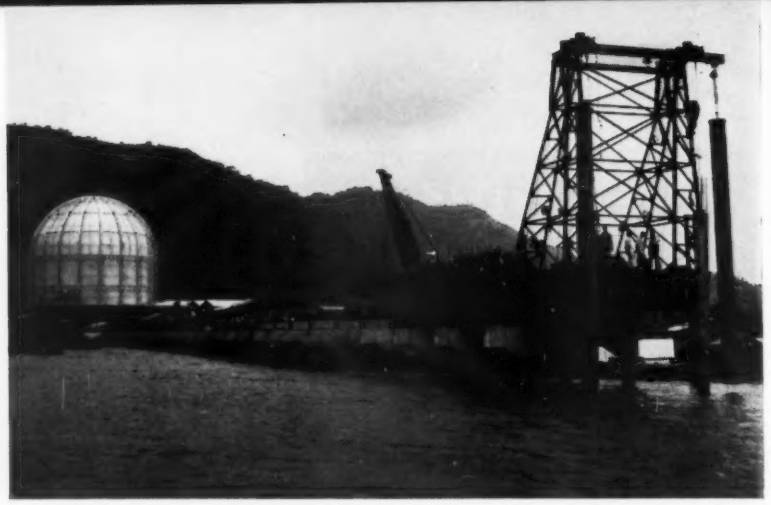
Public enquiries on proposals to build nuclear power stations have become standard practice. They were necessary for the first four CEGB stations and objections have already been received to the latest project—at Sizewell in Suffolk. The Dungeness enquiry will be the first since the decision was made to modify the CEGB stations so that they could produce weapon-grade plutonium if necessary.

Work starts on AGR

Construction of the Advanced Gas-cooled Reactor project at Windscale has now begun and target for completion is mid 1961. Firms participating are: Whessoe—reactor vessel, English Electric—turbo-alternator and associated equipment, International Combustion—heat exchangers, Babcock and Wilcox—containment building, Hick Hargreaves—dump condenser, Mather and Platt—feed pumps, Whatlings—building and civil work. In addition, Ewbank and Partners Ltd (London) have been retained as consultants on the turboalternators and the part of the steam plant within the turbine hall. The project will provide experience for (a) design of the next round of commercial stations and (b) assessment of the possibilities of this type of reactor, which uses ceramic fuel canned in beryllium, for nuclear marine propulsion.

Atomic law to go beyond reactors

The possibility of extending compulsory licensing and insurance to other nuclear installations besides reactors as atomic energy develops further is envisaged by the Ministry of Power; their Nuclear Installations (Licensing and Insurance) Bill, which is now going through the Lords, will enable them to do this by Regulations. At first the only installations likely to be affected by the Bill will be the Central Electricity Generating Board nuclear power plants and any privately owned reactors such as AEI's Merlin at Aldermaston. It places on reactor owners the liability to pay compensation for personal injury or damage to property by radioactivity even when due to unavoidable accident. The liability will be limited to £M5 for each occurrence and the owner will have to cover this by insurance 'or other means.' In the unlikely event of claims exceeding £M5, Lord Mills says, Parliament itself would have to determine how they should be dealt with. The Atomic Energy Authority, as a Government department, will be unaffected by the Bill and its liability for any damage due to its reactors will remain unlimited. Other reactors excluded will be those for propulsion units in ships or aircraft.



A YEAR TO GO The jetty under construction by the Cementation Co for the Canada-India research reactor near Bombay in India will soon be finished; the reactor itself is due for completion by the end of 1959

Under existing law claims must be made in England within three years for personal injury and six years for damage to property. Since damage due to radioactivity might result well after such periods the present Bill fixes the limit for all claims as ten years from the date of the accident.

AUSTRALIA

Mary Kathleen ships first oxide

The first shipment of uranium oxide from the Mary Kathleen mine is now on its way to the United Kingdom. The project, involving construction of a reservoir, an ore processing works and a township in this remote corner of Queensland—no roads or water supply existed when ore was discovered in 1954—has cost about £M10 since the decision to go ahead two and a half years ago. The first oxide was produced last June and the mine has now been officially opened under the management of the Rio Tinto company. Its reserves have been estimated at not less than six million tons of ore containing about 14·3 pc oxide; the UK Atomic Energy Authority supported the project throughout and placed an initial order of £M32.

EGYPT

Uranium, D_2O projects under study

The Government is now actively looking into the possibility of producing its own uranium and heavy water and two International Atomic Energy Agency experts are evaluating the situation. Egypt is rich in phosphates and they would like to know whether the extraction of uranium from these ores might prove a feasible and economic operation. One of the experts, B. V. Nevsky, who is going to advise on this matter, is a member of the department of rare and radioactive metals of the Moscow Institute for Non-ferrous Metals. An ammonium nitrate fertilizer factory is now being constructed at Asswan and the other specialist, Dr Victor Thayer from the US will study the possibilities and the economic interest of producing heavy water by the electrolytic method as a by-product in the operation of the factory. He is a member of Atomic Energy Division of the Du Pont Company and is at present engaged as a heavy water expert at the American Atomic Energy Commission's Savannah River project.

FRANCE

Sub reactor abandoned

Work on the natural uranium-fuelled reactor for a French submarine has virtually ceased. 'It has not given the results expected,' say official sources in Paris; construction of the hull is to go on but the attempt to produce a nuclear submarine unaided by America is likely to be abandoned. The prospects of getting plans and fuel for a US power propulsion unit, however, look a little brighter following recent visits by Professor Perrin, High Commissioner of the atomic energy commissariat, to Washington and the visit to France of a US team of investigators to check up on the effectiveness of the French security system. If the American investigators make a favourable report the US administration may try to persuade Congress to carry out the offer of providing information on the American nuclear submarines which was made a year ago.

If agreement should be reached the US Westinghouse corporation will be in a strong position to benefit; they have just signed an agreement for cooperation with Forges et Ateliers du Creusot—the first between US and French groups in the nuclear field—and a company capable of building complete reactors is to be formed in the near future. Westinghouse already have agreements with companies in West Germany, Italy and Belgium (*Newsdesk* October), and should be able to take early advantage from deals like the US-Euratom agreement.

GERMANY

Overtaking in ship research

A combined reactor and research facility dedicated near Hamburg recently puts Germany well in the running for the development of nuclear-powered shipping. Consisting of a reactor core and four special purpose pools it was designed by US Babcock & Wilcox, and is the largest of its type so far; the research unit is 89 ft long and 20 ft wide and two of the pools are capable of operating at 5 MW. Instead of the conventional double pool arrangement four have been built in series. It was supplied under the 'Atoms for Peace' programme and will use B & W fabricated fuel elements containing 20 pc enriched-U, which is the usual maximum concentration allowed for shipment abroad under terms of the programme. A uranium-aluminium alloy—45 pc uranium by weight—is used in plate-type fuel elements. Each of the pools has a special function: one consists of a standard pool with beam ports and thermal column; another has an exterior chamber for bulk shielding experiments in air, and the remaining two are a storage pool for the reactor core, and an experimental pool in which larger than average equipment and specimens may be immersed for irradiation. The facility is owned and operated by the Society for the Utilization of Nuclear Energy in Shipbuilding and Navigation Inc and is the first reactor to be built in Europe expressly for marine applications.

UNITED STATES

Spevack and Goliath

The series of court actions between the AEC and chemical engineer Jerome S. Spevack on the question of whether or not the Commission is entitled to publish information about its heavy water plants—which use processes discovered by Spevack—is to culminate in a hearing by the Supreme Court. The Commission is operating under a court order restraining it from divulging any details of the processes and say that this has had 'a very substantial adverse effect on it.' Heavy water plants which had been opened to inspection by scientists and technicians have had to be closed again because they included features which might be covered by Spevack's patent claim. For the same reason they had to examine about 1000 reports and reclassify forty of them.

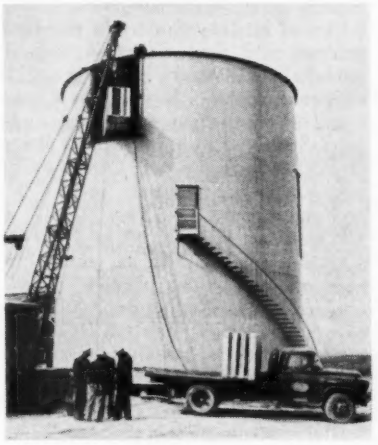
Jerome Spevack invented a dual temperature process of isotope concentration in 1942. Four years later he developed an improved process and in 1949 showed the AEC how it could be applied for a heavy water plant. He filed a patent but it was put under 'secrecy order' by the Commission, which prevented him from taking any steps toward applying for foreign patents. In February 1957 the 'secrecy order' was rescinded and at the same time the AEC declassified the details and announced its intention of publishing. At this point Spevack took the matter to court and the battle is still going on. He is backed by the American Chemical Society and the Engineers Joint Council, who regard the case as containing an important point of principle.

AEC officials say that the restraining order 'greatly limited' US participation in the Geneva conference and is restricting its ability to cooperate with OEEC in its current studies of methods of constructing heavy water plants.

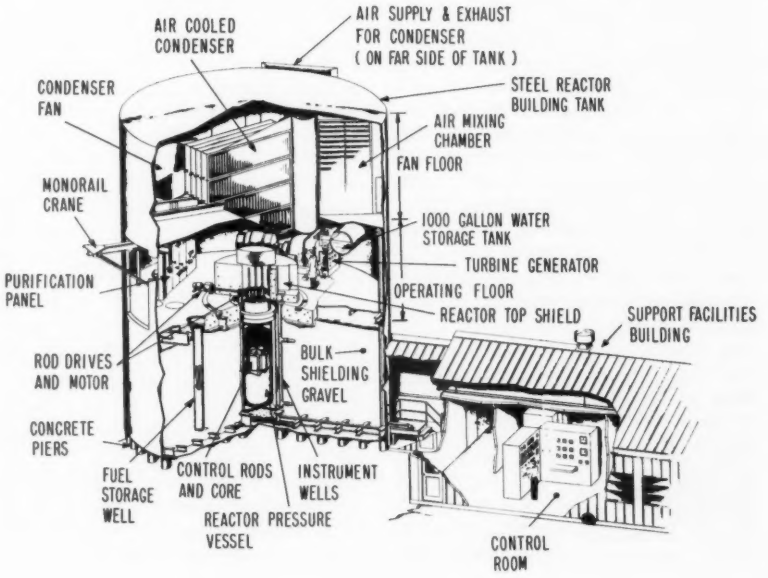
ALPR dedicated

After having been run at low power for several weeks the Argonne Low Power Reactor will be formally dedicated on December 2 at the AEC's National Reactor Testing Station near Idaho Falls. It took just over a year to build, cost £1,980,000. The main point about this 3 MWt direct cycle boiling water reactor is that components of future versions can be easily flown to remote areas for assembly on site—no part weighs more than 20,000 lb—and it will operate continuously for three years on one fuel loading, producing 200 kW of electricity and 400 kW for space heating. No excavation is necessary: ALPR is mounted on a series of concrete piers supported by a concrete slab foundation to simulate the pile support construction that would be used, for instance, in Arctic permafrost regions. Housing is a 38 ft 7 in. dia steel tank 50 ft above the ground. Problems like shielding and water supply have been got round by using ordinary gravel for the biological shield inside the reactor building, and an air-cooled condenser for the turbine exhaust. The design is based on experience gained by Argonne National Laboratory with the BORAX programme of experiments. Present BWR's have operated on a steam bypass control principle—i.e. reactor power remaining constant—but ALPR will soon have a further control system for automatically adjusting the power generation rate. It should thus require a minimum of supervision, besides being simple and reliable to operate.

Most interesting technical innovation is the use of aluminium both for fuel element cladding and the air-cooled condenser. A new aluminium-nickel alloy



A section of the air-cooled condenser is put into the ALPR tank through the air supply and exhaust opening. Perspective diagram below shows main lines of the 3MWt boiling water reactor, the prototype of portable packaged plants for use in remote areas



X-8001 (1 pc nickel) developed by Argonne is employed not only for fuel element cladding, but for fabricating almost the entire core. It is expected to show good corrosion resistance at the ALPR operating temperature (440°F at plate surfaces) and reduce power costs, being cheaper to fabricate and process than most other cladding elements. The aluminium plate fuel elements are assembled into roughly 4 x 4 in. boxes, and the meat of the sandwich consists of highly enriched-U again alloyed with aluminium, this time containing 2 pc nickel.

Mass production of BWR's proposed

A plan for a $M500 crash development programme of the boiling water reactor with the aim of making nuclear power economically competitive in the US by 1965 has been disclosed by the General Electric company. It proposes manufacture of fifty or more 5 MW packaged reactors on a mass production basis at $M4–4½ each—delivery by GE to utility companies to begin in just over a year—and a construction programme leading to three full scale commercial plants of 450 MW or so by 1970. Cost of these, said GE's vice-president, Francis K. McKune recently, would be $175–225 a kW with fuel costs of 1·7 to 2·2 mills a kWh. He declared that the scheme has been received 'enthusiastically' by executives of several utility companies who have been contacted privately. It is now being presented to the Government and industry on a broad scale.

Competitive by 1965

Giving details, he said the scheme was divided into two parts: a development programme to make boiling water plants competitive with conventional power stations in much of the country by 1970 and in some parts as early as 1965, and a construction programme of small units to accelerate operational experience. Cost of the first part would be $M128 over a period of seven years, the money to be found largely by industry. By 1962 five 'developmental' plants would be built, each designed to attack the problem from a different angle: (1) the 50 MW reactor the company's Atomic Power Equipment Department is designing for the Humboldt Bay Power Plant. This plant will exploit the cost reduction potential of system simplification. (2) a 25 MW compact plant to study cost cuts through reduction in physical size (3) another 25 MW high-power-density plant to investigate the possibilities of reducing capital cost by doubling power output per unit reactor core volume (4) a 100 MW or larger high-power-density plant to test power density limits obtainable in a medium size reactor and to provide a full-scale test of high power density fuel and (5) a 50 MW separate nuclear superheater used as a 'hook-on' reactor to an existing boiling water plant to demonstrate characteristics of a superheating reactor in conjunction with boiling water reactors.

Next step in the programme would be operation by 1965 of three large-scale 'evolutionary' plants to incorporate advances made in the developmental plant series. These, which might include a 100 MW natural-circulation plant, a forced-circulation 200 MW and a 325 MW superheater plant, to be competitive for the electric utilities that operate them by producing power at about 8½ mills a kW hour. Finally, McKune said, 3 'target' plants would be put into operation by 1970 to produce power for 6½ mills a kW hour.

For the second part of the programme, designed to give widespread operational experience of the BWR by the time that economic large scale plants became available General Electric has already designed a small 5 MW plant based on the Vallecitos reactor. It is suitable for mass production and the company is prepared to build up to 25 and expects that other manufacturers would be able to at least match this number.

1970 is the year fixed by the AEC for the achievement of competitive power by industry. 'If we don't better that date,' McKune said, 'at least this plan provides that we'll hit it.' The company believes that the BWR is the most promising reactor type and could give the US a decisive world lead in atomic energy development.

RUSSIA

A slow ride to the moon?

The idea of an atomic-powered space rocket is referred to by Anatoly Karpenko, scientific secretary of the USSR Academy of Sciences' commission on interplanetary travel, in the magazine Zvezda ('Star'). He discusses the possibility of putting into orbit around the earth a small rocket with a nuclear generator and an electric motor. Such a rocket, in Karpenko's opinion, could fly into space in an unfolding spiral to approach the Moon in five months. The propulsion system, Karpenko says, would have to be based on the principles of electric acceleration of reactive jet particles. The electric energy to power such motors could be generated both by nuclear alternators and solar batteries installed in the space rocket. He recalls experimental investigations by Academician Valentin Glushko who, on the basis of his theoretical studies, built an engine as far back as 1928 powered by separately generated electric energy with the working medium made of various metals and electrically conductive liquids fed into the combustion chamber.

INTERNATIONAL

Seven experts will guide IAEA

Any technical points arising out of the International Atomic Energy Agency's programme will be dealt with in future by a seven-man advisory team. The decision to establish their own committee was taken by the Board of Governors in September and the question of membership has been settled by simply appointing the scientists who already serve on the Scientific Advisory Committee of the UN. They are: Prof H. J. Bhabha (India), Sir John Cockcroft (UK), and Professors U. S. Emelyanov (USSR), B. Goldschmidt (France), B. Gross (Brazil), W. B. Lewis (Canada) and I. I. Rabi (US). A spokesman for the IAEA says the duplication is deliberate and intended to tie the Agency in still further with the United Nations. The committee has already got down to work; at a first meeting in New York on Nov 14 they started going over the long-range IAEA needs for technical facilities—including the proposed establishment of a functional laboratory—looking round for fresh research activities and studying the feasibility of one of the present proposals: an estimation of the world-wide distribution of hydrogen-oxygen isotopes in water.

New head for IAEA governors

Twenty years a diplomat, Carlos Alfredo Bernardes of Brazil has been elected unanimously as chairman of the IAEA Board of Governors for the next year. He helped draw up the statute of the Agency in the original New York meetings in Sep 56, and has served since then as Brazil's representative to the Board of Governors. New vice-chairmen are Wilhelm Billig (Poland) and Nazir Ahmad (Pakistan)

US-Euratom target postponed

The final move in the six months of constitutional and diplomatic manœuvres

John A. McCone, US AEC chairman, signs the agreement committing America to supplying Euratom with up to $M135 for reactor construction and enough fuel for 20 years. Left and right are Italy's Enrico Medi and M. Krekeleer of Germany

developing Euratom's cooperation programme with the US took place in Brussels on Nov 8 with the signing of an agreement. It follows the lines of the draft published in the summer (*Worldview* August) providing for the construction of six to eight 100-150MW reactors—probably pressurized or boiling water types — in the various Euratom countries by 1963. The US is supplying Euratom with enriched fuel for the reactors on deferred terms and a credit of up to $M135 for construction which will be reloaned to the countries concerned; this amounts to just over a third of the total estimated cost of the programme. One of the reasons for the lengthy negotiations was Euratom's insistence on inspection rights and America's reluctance to relinquish them. The US has finally given way on this point and inspection and control will be the exclusive responsibility of Euratom. But it may now be too late to reach the original figure of 1000 MW installed capacity by 1963 and the agreement just signed specifically recognizes that the target date may have to be put back by two years.

The Joint Atomic Energy Committee of Congress is expected to give its final approval before February 1 and talks between Euratom and US experts have already begun: it is hoped that preparations for construction of the first reactors will be completed during 1959. The next step is for private industry in the Euratom countries and the US to submit proposals for reactor projects.

The agreement gives some pretty solid benefits to both sides: Euratom countries will get a cheap boost to their atomic power programmes; America will gain experience on large scale reactors which the lower cost of conventional power in the US makes it less economical to build there—and incidentally get a firm foothold for her future atomic export market.

At the end of the Brussels signing ceremony John A. McCone, US AEC chairman, presented Euratom with a 19,000 volume library on atomic energy. 15,000 of the volumes are in fact microfilms and a reading machine went with them. The library will be kept up to date with periodic supplements by the AEC.

WORLDBRIEFS

● **Antarctica** A $M5 nuclear power plant is to be constructed by the US at McMurdo Sound.

● **Belgian Congo** The US General Atomics TRIGA research reactor which was exhibited at the Geneva conference has been bought for the University of Lovanium at Leopoldville.

● **Brazil** The University of Minas Gerais at Belo Horizonte has ordered a 30–100 kW TRIGA reactor from US General Atomics. It will be a below-ground version.

● **France** Industrial groups plan to start bidding now for the first nuclear power stations to be built in Holland and West Germany; they will offer gas-cooled graphite-moderated reactors.

● **France** The 2500 MeV synchrotron SATURN has been inaugurated at Saclay.

● **Ghana** It is reported that the government plans to investigate the possibility of establishing a cheap and relatively small nuclear power station in Ghana.

● **Italy** An official ground breaking ceremony for the nuclear power plant to be built by the UK Nuclear Power Plant Co will take place at Latina on Nov 20. Work on survey and approach roads for the station has already begun.

● **India** The contract for a heavy water plant has gone to a German firm—Linde's Eismaschinen.

● **Japan** The Atomic Energy Research Institute has retained the Internuclear Co of Clayton, Missouri, US, to provide engineering services connected with plans to buy a power demonstration reactor.

● **Norway** The Oslo Utility company is sponsoring a study of plans for an atomic heating plant for the city.

● **New Zealand** A white paper on the power situation states that natural sources of power will render atomic power unnecessary and uneconomical for some years to come.

● **Russia** Dr Mikhail Lavrentyev, leader of the Siberian section of the Academy of Sciences said recently that a 'tremendous success' has been achieved in fusion research.

● **Russia** As foreshadowed in *Worldview* Sep, nuclear power is apparently to play only a comparatively insignificant part in the new seven year plan announced by Prime Minister Khruschev to the 21st Congress of the communist party recently. He spoke about 'far reaching measures for the peaceful applications of atomic energy' and a number of nuclear stations with 'different types of reactors.'

● **United Kingdom** Headed by Ladislav Rehacek, deputy Minister of Power and Water Supply, a group of Czech technicians recently visited Calder Hall and the Bradwell site. Rehacek said power demands in Czechoslovakia were doubling every seven years and nuclear power was needed, particularly in Slovakia, where industry is rapidly expanding.

● **United Kingdom** In a five day visit John McCone, chairman of the US AEC and Dr Willard Libby, a member of the commission, toured nuclear power stations and held discussions with the Atomic Energy Authority.

● **United Kingdom** The Tube Investments Technological Centre at Walsall has fabricated a small bore beryllium tube of sufficient ductility to permit bending it on a 5-inch radius. The tube is of 0·300 inches bore with a wall thickness of 0·040 inches.

● **United Kingdom** A nuclear power station simulator is to be built by Elliott Bros (London) Ltd for the CEGB; it will be used for training operators for the Berkeley and Bradwell stations and subsequent stations of similar type.

● **United States** The AEC has invited proposals from industry for research and development programmes and a design for a fast breeder reactor using a plutonium oxide-uranium fuel cycle. The objective is to get cheaper power from FBR's by reducing fuel cycle costs.

● **Uruguay** The UTE—General Administration of Electrical Works and Telephones—is actively considering the use of nuclear power stations of about 100 MW capacity.

Is Britain on the right track?

a critique of our nuclear

by K. L. STRETCH, M.A., LL.B., A.M.I.E.E.
Director, Central Engineering Establishment, National Coal Board

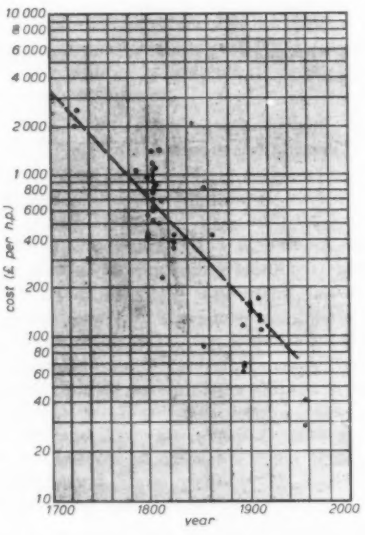
DESPITE THE GREAT FUTURE for the generation of power from nuclear fuel, it is important to realize that the full potential value will only be achieved if exploitation is kept on sound technical and economic lines. This problem is particularly critical in Great Britain, in view of our precarious economic position and the fact that the size of our industrial resources prevents us from carrying out the widely based programmes adopted by our main nuclear competitors.

Technically, Britain's present leading position in nuclear generation is a tribute to the sound lines followed in the development stage of the art, but some of the forecasts being made raise doubts whether the economic exploitation is being well planned. Our present need is not for a series of *Great Easterns*—technically outstanding and well ahead of any comparable overseas effort but financial and operational failures—but for a steady build-up of power resources to provide the manufacturing capacity by which we live with as cheap a source of power as possible. It is therefore essential to examine the briefs being presented to see if the very optimistic forecasts are indeed justified.

Is Hinton correct?

The starting point for such a discussion must be Sir Christopher Hinton's Axel Johnson Lecture given in Stockholm in March, 1957 (*1*) particularly as his opinion must carry great weight in the Ministry of Power and the projected nuclear programme announced seems based on the analysis that he proposed there. The paper was indeed a valiant attempt to reduce crystal gazing to a science. Unfortunately Hinton's high reputation has discouraged the ruthless examination of figures, assumptions and techniques, which a paper of this importance demands. As a result, his suggestion that nuclear power would be cheaper than coal-based power by about 1965 is now quoted as an established fact and the whole of our power generating programme is being geared to it. The first part of this article is a critical review of his analysis, leading to the conclusion that it is grossly over optimistic and that planning on such a basis would seriously prejudice this country's economic future. In fairness one must admit that Hinton himself would already appear to be hedging some of his forecasts, possibly in the light of his translation to the CEGB. The second part will suggest some aspects of the nuclear programme which need greater attention if it is, in due course, to be the technical credit to Britain and economic salvation which it should be.

Hinton plots the cost per h.p. of steam and diesel engines reduced to 1954 prices (figures 1 and 2), and deduces that technical advances can be expected to produce halving times for the cost of such capital equipment of the order of 20—40 years. The analysis clearly depends on the method of correcting for the changing value of money, but sufficient figures are included to deduce the conversion factors used.



Capital cost of steam power stations on 1954 equivalent—Hinton (Fig 1)

The real cost of engineering products

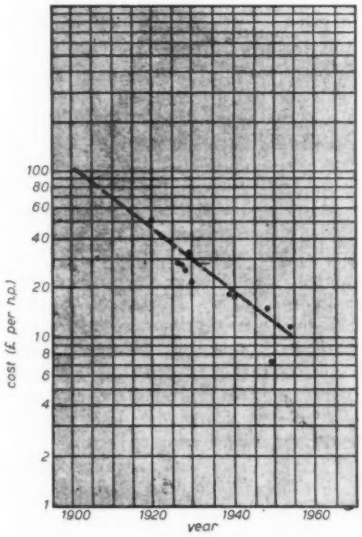
One method of testing this thesis is to assume that it is valid and apply it to one's own experience in designing and ordering mechanical equipment. It has been a common estimating practice to calculate on 1939 prices and correct them for the rapid rise in costs between then and the expected time of delivery. The trend postulated would suggest that engineering equipment should have shown a drop in price in real terms by a factor of about 0·7 between 1939 and 1954, which, applying the conversion factor for the fall in the value of money of 2·4, would suggest that comparable mechanical equipment could be bought in 1954 for 1·7 times the 1939 price. The author's own experience over just this period is that the correct conversion factor to give the 1954 actual money prices should be about double this figure, and most private indices consulted give factors of the same order. Such a discrepancy suggests that there must be a serious error in either the predicted rate of reduction in cost due to technical advance or in the price correction factor.

Why cost figures are unrealistic

Examination of the data given for figure 1 quickly indicates a reason why the slope deduced may be quite inaccurate. The details given show this is not an assembly of comparable prices from which any trend can be deduced but a motley collection of unrelated prices which do not warrant their description as data on steam power stations. Only the most recent point approaches that description, and the exact content of the price even here is not defined. The remaining points are an odd collection of different types and sizes of engine, some with boilers and some without, with no common factor but steam as the operating fluid. So far from this arbitrary assembly justifying

As Works Manager of Calder Hall from 1954-1957 Kingsley Lewis Stretch was responsible for recruiting and training operations staff, inspection during construction, commissioning and running the station. He left the AEA in September, 1957, to rejoin the NCB

power programme



Capital cost of land-based oil engines on 1954 equivalent—Hinton (Fig 2)

the deduction of any trend, as wide a scatter could be obtained from quotations at any one given date.

Figure 2 looks more coherent, but the trend indicated cannot be attributed to technical advances: other factors must first be discounted. Over the 30 years spanned, variations in type and duty, size and quantity, of the engines provided would, and probably did, produce shifts in the average cost per h.p. as great as those recorded. As the last two factors in particular have both been operating and both tend to reduce the costs quite independently of any technical advance, it is safe to say that the rate of reduction in capital cost due to technical advance is very much smaller than that predicted.

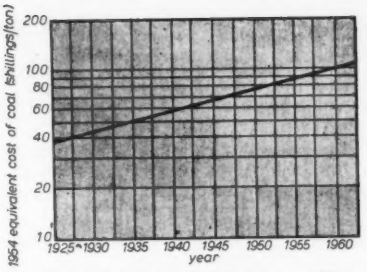
Size is the main factor

In fact it seems probable that the entire gain indicated can be attributed to the steady increase in size, if it can be assumed that these units follow something approximating to the 0·6 power law, which is often used for scaling up costs in large process plants (*2*). Moreover the same factor would fully explain away the reduction in capital cost referred to in Strath's Geneva paper (*3*). While this increasing size factor might indeed continue to operate for a time, it is doubtful whether it is wise to aim at even larger units than those now being installed (about 250 MWe per reactor) until the reliability in service, and therefore the plant availability, has been more rigorously proved. The advantage in capital costs may well be completely offset by the cost of keeping coal-fired stations standing by in case large blocks of generating capacity were suddenly taken off the system.

It is fair to say that the type of analysis proposed in the Axel Johnson paper is a useful approach to the problem of forecasting trends, but that unless the facts are more carefully assembled and the analysis is carried out more critically—for instance by ensuring that the figures relate to comparable machinery and that they have been properly corrected for non-technical factors—they cannot justify the value at present being attached to them. In fact such detailed analysis seems likely to indicate that, apart from the effect of increasing size or numbers, there is no overall trend at all. Specific technical advances may give sudden variations in any given technology, but the effect over a period of years varies in a random way between different classes of machinery. However, consideration of the effect of the factors which have been ignored, and comparison with one's normal experience, indicates that the trend deduced is very over-optimistic.

Comparison with coal unfair

In the analysis of the fuel costs of the two types of station, neither the rate of rise of coal costs nor the fall of nuclear fuel costs has any justification at all. Hinton's graph (figure 3), which is used to predict the fuel cost in coal-fired stations, is inaccurate in starting point and trend. It shows a coal price in 1957 of 90s. per ton in 1954 values. In fact the CEGB report for that year indicates that the actual cost of coal was just under 80s. in 1957 values. It also suggests a doubling time for the cost of coal of about 25 years, despite the fact that



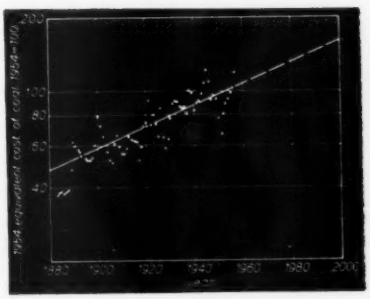
Estimated rise in cost of coal on 1954 equivalent—Hinton (Fig 3)

the text admits the unreliability of using this particular short time base. Figure 4 shows a more accurate analysis taken from the Coal Board's own records over the past 75 years, giving a doubling time in real terms of about 70 years. Hinton's estimate of costs from conventional stations (Table 1), therefore, charges them with fuel costs which even at the earliest date are too high and rise at far too rapid a rate.

The cost of high burnup

Against this, the cost of nuclear fuel is shown falling at an equally dramatic speed (Table 2). No evidence has yet been produced to justify such a forecast, and there are, indeed, many indications to the contrary. Although the AEA has released little information on this subject, it should be safe to take their latest published figures and assume that, from that source, they will be by no means biased against nuclear fuel. Jukes in his Geneva paper (*4*) quotes a figure of £20,000 per ton for natural uranium fuel, one that is similar to Hinton's starting point; but Jukes clearly indicates that this is the price for Calder Hall-type fuel elements, which are not irradiated to the 3000 MWd/Te needed to produce Hinton's fuel cost of ·24d/unit. While there is no reason to doubt that methods of attaining 3000 MWd/Te will be found, there is equally no reason to assume that the improvements needed to achieve this figure will have no effect on the cost. While advances in

Revised cost of coal graph (corrected to 1954 prices) from NCB figures—Stretch (Fig 4)



THE PRICE OF POWER—2 views

TABLE I From conventional stations—Hinton

COMMISSIONING DATE	1960	1970	1980	1990
Depreciation on interest on capital	0·12	0·11	0·09	0·08
Fuel costs	0·44	0·52	0·60	0·72
Operating expenses	0·04	0·04	0·40	0·04
Total	0·60	0·67	0·73	0·84

TABLE II From nuclear stations—Hinton

COMMISSIONING DATE	1960	1970	1980	1990
Depreciation	0·37	0·30	0·26	0·22
Interest on fuel charge	0·06	0·04	0·03	0·02
Fuel replacement charge	0·24	0·13	0·08	0·06
Operating expenses	0·06	0·05	0·04	0·03
Total	0·73	0·52	0·41	0·33
Credit for Pu in irradiated fuel	0·07	0·05	0·03	0·01
Net	0·66	0·47	0·38	0·32

TABLE III From conventional stations—Stretch

COMMISSIONING DATE	1960	1970	1980	1990
Depreciation and interest on capital	0·12	0·11	0·09	0·08
Fuel costs	0·40	0·39	0·38	0·38
Operating expenses	0·04	0·04	0·04	0·04
Total	0·56	0·54	0·51	0·50

TABLE IV From nuclear stations—Stretch

COMMISSIONING DATE	1960	1970	1980	1990
Depreciation	0·37	0·30	0·26	0·22
Interest on fuel charge	0·06	0·04	0·03	0·02
Fuel replacement charge	0·24	0·24	0·24	0·24
Operating expenses	0·06	0·05	0·04	0·03
Total	0·73	0·63	0·57	0·51
Credit for Pu in irradiated fuel	0·07	0·05	0·03	0·01
Net	0·66	0·58	0·54	0·50

costs are in pence per kWh sent out

metallurgy have contributed largely to reducing capital costs where the cost of the metal is only a small fraction of the total cost of the plant and is more than off-set by the increase in performance, a different relation will exist where the metal is the fuel itself, and so an increase of cost to attain higher performance will affect the whole cost of the fuel. The assumption which is inherent in Hinton's fuel figures, that the higher irradiations can be achieved with no increase in cost of the fuel, has no evidence to support it, and is in conflict with the normal experience of metallurgical progress.

It is also questionable whether the plutonium allowances at present being postulated are in fact justified by any foreseeable non-military use. In fact reprocessing costs, particularly with more robust canning materials and alloyed fuel, may more than off-set any theoretical return from this source.

Plant availability vital

It is, above all, inaccurate to compare nuclear- and coal-fired costs, basing those for nuclear stations on base load working and leaving the coal-fired stations to pick up the entire peak load. Such costing is no doubt legitimate within an existing organization to determine which of a given range of stations should handle which part of the load, but it is quite unrealistic to claim that nuclear power is cheaper than coal-fired power if the former is allowed to cream the load. Moreover no analysis is made of the vital problem of plant availability, which will assume greatly increased importance with nuclear stations in view of the large block of power which is tied to a single source of heat. The effect on this factor of introducing the moving machinery necessary for charging and discharging on load is quite inadequately discounted, particularly as it marks a complete change from the policy successfully used at Calder where, during power operation, the only moving items inside the reactor were the control rods.

Parity with coal not till 1980's

It is also unfortunate that all the costing is carried out on an artificially low scale of capital charges, which has already encouraged far too much soft thinking in this country on the size of return which should be expected from capital investment. Lastly, and possibly most important of all, the nuclear stations are not yet carrying their full research and development charges, if indeed they are carrying any at all. While the coal fired stations carry the full cost of any such development, the cost of the work carried out by the AEA is charged not to the nuclear stations but to the tax-payer, while it is probable that a considerable proportion of the overhead costs of developing and designing nuclear power even within the consortia are charged on to the conventional stations.

All these factors indicate ways in which the picture as presented by Hinton in Tables 1 and 2, is seriously biased in favour of nuclear power. Not all of them are reducible to arithmetical terms, as either the information for the full analysis is lacking or the basis for forecasting is too weak to stand the strain.

Tables 3 and 4, which give revised figures for Hinton's Tables, have been prepared by accepting his analysis in full for all factors except fuel charges, despite the probability that his rate of reduction of capital cost and plutonium credits are too favourable to nuclear power. Having credited nuclear power with this, it is reasonable to withhold any further advantage from quite unfounded predictions on nuclear fuel costs, and to correct the forecast of coal fuel costs to fit the more reliable figures available. These revised figures indicate that nuclear power will only be economically competitive with coal based power in 1980/90. Clearly it is possible to hope that some unforeseen technical change may bring the date somewhat earlier, but Tables 3 and 4 can be taken to represent more accurately present knowledge and present trends. One must also remember that any major technical advance may, while favouring nuclear power against coal-based, favour other forms of nuclear reactor rather than the gas-cooled graphite-moderated type.

More experience needed

It is, therefore, extremely rash for this country to rush into building a large number of obsolescent nuclear stations in the belief that they will solve the fuel problem. Until near the changeover period only enough should be built to enable us to continue to acquire operational experience, and to assist the initial build-up of nuclear fuel. The latter may not be economically justifiable, but it may be essential for the UK to compete with the American and Russian production of high grade nuclear fuel from very much cheaper sources of electrical power. It is misleading to suggest that any larger programme will be a cure for the existing power shortage, even if that phantom really exists. For a much longer period than

is now being suggested the building of nuclear power stations will increase the cost of power, and this increase in cost is only justified by the more distant prospects.

Our wasteful fuel habits

As far as the short term prospects over the next 10 years or more are concerned, a vastly better solution is to concentrate on a more economical use of the existing sources of fuel. It is likely that such factors as the rent de-restriction and clean air acts will have a much greater effect on our fuel position, by providing economic benefits for the efficient use of fuel and sanctions against wasting it, than nuclear power can do at the present stage. Most of the forecasts of fuel requirements are based on extrapolating from existing usages. These figures have been assembled during a period when coal has been cheap and the country has adopted habits of using it wastefully, so there is no cause to rush into panic measures to allow our industrial expansion to be based on the same bad practices. It is much better to correct the existing faults and encourage a more conservative and economical use of existing resources, so that the needs of expansion can be handled without the need for uneconomical remedies and, at a later stage, the rate of expansion now postulated can be maintained with a smaller fuel demand.

The problem of management

Meantime, there is no disagreement that in time the change over to nuclear power being the more economic source must indeed take place. In fact anyone viewing our economic position must be anxious to bring it forward, as the sooner one can avoid burning our best chemical raw material to provide heat, the sooner the country will be more soundly and securely based. It is worthwhile, therefore, to turn to some discussion of aspects of the nuclear programme which need more attention if this is to be driven forward as quickly and efficiently as possible.

Neither the AEA nor the Fleck report (*5*) show any sign of realizing either the importance of a rapid rise in the operating standards on our industrial reactors, or of what is the root of the existing trouble. While an improvement can be expected when the CEGB plants start operating, with the Board's greater background of operating to the high standards normally expected in public utility organizations, the present delay in achieving those standards will have serious repercussions on the whole nuclear development programme.

The heart of the problem is the quality of the management on the plant, the provision of adequate staff to enable the works management to carry out its duties efficiently, and the provision of a superstructure above the works management which, while providing the necessary control and service facilities, still enables the Works Manager to discharge his duties efficiently. A mere increase in the titles, salaries and numbers of the upper echelons of the hierarchy may indeed be detrimental to the efficient management of the plants by distracting the Manager from his duties and by encouraging the promotion of sectional interests, which are fatal to the integrated and safe control of the plant.

The provision of adequate operational management is particularly important for two main reasons. The first, particularly vital at the development stage, is that a rapid and accurate feedback of operational experience is essential if development is to be kept on the right lines. While initially a technology must be based on research work in the laboratory and design work on the board, once it reaches the operating stage major developments depend largely on the results of full scale operating experience. The widespread belief in the AEA that all engineering progress is made in the drawing office and laboratory is very far from the truth. It is disturbing to note in Sir Leonard Owen's Geneva paper (*6*) that this fallacy is still believed—in his interesting account of the method by which his design groups work there is no mention of liaison with the operations branch at all. It is strange that in a sporting country such as our own, we should have forgotten the importance of the race-course test as a means of confirming or modifying the ideas of breeders and trainers.

Weak links must be eliminated

Moreover this lack of appreciation of the operational aspects of development work is a major factor in promoting some of the over optimistic estimates for nuclear power, as the time needed for rigorous operational proving is badly underestimated, and the economic consequences of a failure in service are too easily glossed over. This testing assumes greater importance as nuclear reactors become more complex, as a greater allowance must be made for testing, both in time and over a wider range of operating conditions, to ensure that all weak links have been eliminated before the achievement of a successfully proved industrial design can be claimed.

In carrying out this aspect of a development programme the quality of the operational staff is of overriding importance. Mere repetition of masses of figures or statements of what has happened is of little value in deciding the future course. What is needed is the clear analysis of what has happened in the light of the design criteria and the scientific basis of the plant, so that any recommendations and suggestions are digested and not conditioned by irrelevant or transient considerations. This function is particularly important in a programme such as Britain's which is advancing on a narrow front and cannot afford to be misled by any false indications.

Instrumentation is not enough

The second important consideration is the establishment of safe operating standards for these plants. The nuclear industry has much to learn from other branches of engineering, where there is a greater experience of operating complex engineering plant. Some of their potential dangers are markedly higher than the nuclear industry seems to realize, as they fail to appreciate that the danger is already being contained by the operational standards which have been established. Here again the problem is to obtain men who can understand and coordinate the complex as a whole, as incidents and dangers usually arise where there are misunderstandings or failures to cooperate between some of the inevitably separate functional aspects or responsibilities within the organization.

It is, therefore, important to have a man capable of understanding the whole plant, and to ensure that he is provided with staff and authority to enable him to exercise integrated and effective control. Any idea that increased instrumentation and technical advances will automatically solve these problems is quite false, as is also the suggestion that paper chains will do the job. Indeed each new technical advance or additional piece of equipment increases the complexity of the whole, and makes the control problem more difficult. The Fleck recommendations, based as they appear to be on the fallacy that the control of nuclear stations can be broken into a series of unit processes, miss this point, and the proposals will, indeed, make safe and efficient control more difficult. The primary problem is not a question of containing an incident when it occurs, although arrangements must be

made for doing this, but of ensuring that the plants are operated so that incidents do not occur.

More test facilities required

Greatly increased resources should be devoted to establishing, and promoting throughout industry, the very greatly increased standards of reliability which will be demanded of any items intended for use within the reactor or its closely associated circuits. Consideration should be given to providing extensive inactive testing facilities, possibly on the lines of aircraft engine type testing. Installing such items as charge and discharge gear, control gear, instruments and other components which must operate for long periods under onerous active conditions without such proving will lead to some very expensive correction at a later date. Power stations have had, to a large extent, to be their own test beds and in some aspects this will continue, but if this is necessary the economic assessment of such stations must be debited with some very high development charges. The cost of trouble on a reactor may be so high, particularly if the trouble is precipitated when it is on full load, that it may be cheaper to pay even the high price of such testing facilities as have been indicated to eliminate a large proportion of the snags before the equipment goes active. Clearly, like the establishment of the standards of clean conditions needed in nuclear work, these reliability standards will ultimately spread their benefit throughout the whole of industry. But the initial effort and expenditure must come from the nuclear industry which has the immediate demand for the increased standards of performance.

Where the GCR is best

Some of the over-optimistic forecasts of costs of nuclear power are likely to rebound very awkwardly for this country. Even if they give us some immediate tactical advantage in trying to sell our pattern of nuclear stations overseas, by basing our whole case on the illusion of cheap power we weaken our own competitive position. As long as overseas buyers are committed to the country of origin for fuel and fuel processing, we shall always be in a disadvantageous position in relation to the US and USSR who, with cheaper power and a larger scale of operation and production, will always be in a position to undercut our fuel prices. Hinton puts this point very forcibly in his World Power Conference paper (7) by describing the sale of enriched uranium fuel for overseas reactors as 'exporting electrical energy in the smallest and most convenient package'.

The one unquestionable advantage of the gas-cooled, graphite-moderated, natural uranium reactor is that it is by a very long way the best type for any country starting installing reactors and wishing to build up a balanced nuclear industry of its own. Very probably many overseas countries would not want to burden themselves initially with fuel manufacturing and processing; but with the knowledge and assurance that such assistance would be available when needed and that they were following the easiest route to the creation of a balanced nuclear industry, they would have much stronger reasons for preferring the British pattern. Moreover it is important to widen the base on which our fuel manufacturing and processing is carried to ensure that competitive standards are met in the interests of our own nuclear power industry.

Need for new-type consultants

It is also important to consider whether the present consortia pattern is the best method of developing our nuclear industry. The most attractive alternative solution—that of building up adequate consulting services in this field—faces difficulties due to the fact that the consultants themselves are wedded to 19th century methods of professional work. There is, however, no reason why they should not maintain their professional standards yet build up the greater financial and industrial resources needed to stand on the same footing as the large, necessarily foreign-based, consulting-contracting organizations. As well as providing overseas customers with an independent advisory service on the selection of suitable equipment, we might, even within this country, get better service from organizations which are free to choose the best components or designs on purely technical grounds, rather than having to patronize their group's own production units.

Waste problems must be faced now

Inadequate attention is being paid to the potentially serious problem of the large fission product disposal facilities which will be needed if the vast increase of nuclear power generation being postulated throughout the world is to be implemented. The present economic assessment of station operation is based on the present cheap methods of disposal. These are tolerable at present, but will be quite inadequate in the long term. There is a danger that, like the problem of sewage on the South coast, the failure to provide adequate long term disposal facilities at an early stage will lead to either greatly increased expense or a steady deterioration in health standards at a later stage. It is important, therefore, that this problem is faced now, despite the fact that it is not yet serious, because unless this aspect is included, a false picture of the real economics of nuclear generation will be provided. Vague calculations of the ultimate capacity of the ocean based on optimistic assessment of allowable irradiation are irrelevant to a problem which will be concentrated in a particularly dangerous fashion in the waters of the European continental shelf.

Britain's great advantage

These suggestions are made to try to improve the balance of Britain's nuclear development programme. Great Britain has gained a great technical advantage in the way she has made up lost time and by the Calder Hall development put herself in the forefront of nuclear development. It would be tragic if unsound analysis of the economic prospects or attempts to snatch quick returns, political or economic, should deflect attention from the true position and the amount of work still needed to be done before economic exploitation is possible, and we should lose the advantage that has now been gained. It is worth remembering that while there was nothing wrong in the idea of increasing the production of vegetable oils in Central Africa as a contribution to the local economy and the world supply of fats, forcing the pace of that development to suit political rather than technical and economic criteria reduced our childhood's friend, the groundnut, from a source of wealth and nourishment to a term of vulgar abuse.

The views expressed in this paper are the personal opinions of the author, and do not represent any official views of the National Coal Board.

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Last month a symposium was held in Manchester, sponsored by Ekco Electronics, to discuss the use of liquid scintillation counting. This method has progressed to the stage where commercial instruments are available and the ease of measurement is a main reason for the revival of interest in radioactive hydrogen as a tracer element. Outlined here are the problems involved in measuring low energy beta emitters by this new technique and its possible future applications in science and medicine

Liquid scintillation counting for tritium and carbon-14

by C. P. HAIGH, Ph.D., F.Inst.P.

SCINTILLATION counting depends on the ability of certain chemical compounds, known as phosphors or scintillators, to emit discrete amounts of light during interaction with ionizing radiations. There is a great variety of scintillation materials (*1*), both organic and inorganic, and although the amount of light emitted per event is small and dependent on the nature and energy of the exciting radiation, it is possible to convert the scintillations into useful electrical pulses by means of a photomultiplier. The resulting instrument is a particle detector of great sensitivity capable of high rates of counting and of energy measurement.

Scintillation materials

Modern scintillation counters have been developed over the past ten years. The first phosphors were solids such as crystals of anthracene, stilbene or thallium-activated sodium iodide and of these the inorganic materials were superior for gamma rays whilst the organic crystals had shorter resolving times. In 1950, Reynolds and Kallman, working independently, found that dilute solutions of fluorescent substances in aromatic solvents, for example p-terphenyl in toluene, were good scintillators. They could be used in large volumes and were more easily prepared and handled than the solid crystals which they have now replaced in many applications.

It followed logically that radioactive materials might be added to liquid scintillators with the prospect of high counting efficiencies. This extension of the scintillation technique has been developed into a powerful method, especially for beta rays. It is the basis of a new method of measuring isotopes such as tritium and carbon-14 and now that suitable commercial instruments are available it is growing rapidly in importance.

Use with low energy beta emitters

Tritium is the only radioactive isotope of hydrogen. It emits beta particles of spectral end point 18 keV and in common with carbon-14 (155 keV) it is an important tracer element which has presented severe problems of measurement. The low energy of the beta rays results in considerable absorption in a solid sample and tremendous difficulties in the construction of suitable window type beta counters. For this reason gas phase counting (*2*), in which the samples are converted to hydrogen or carbon dioxide, has been widely used although it is tedious and unsuited for routine work.

In the scintillation method the sample is dissolved or suspended in a liquid phosphor so that effectively there is no barrier between the beta emitter and the detector and self-absorption in the sample is, to a large extent, overcome. The elements of the system are shown in figure 1. The liquid phosphor and radioactive sample are placed in a container which is transparent to the scintillations. These are transmitted to the photomultiplier tube via an optical coupling fluid, such as liquid paraffin or a silicone oil, whose function is to provide a uniform refractive index between the phosphor and the photocathode and so avoid light loss at glass/air boundaries. The reflector increases the amount of light received by the phototube.

In the photomulplier, electrons emitted from the photocathode are multiplied by secondary emission from a number of dynodes. The gain is such that a single photoelectron may be amplified to a degree which permits further amplification by electronic means: in terms of output current, sensitivities of 2000 amp/lumen may be obtained from a 13-stage tube. This is sufficient to detect the relatively feeble scintillations produced in the phosphor by tritium beta rays but at this level the pulses are of the same order of size as those due to thermionic emission from the photocathode. The problem is therefore one of achieving an acceptable signal/noise ratio in the system.

The thermal background varies considerably from one photomultiplier to another. It is low enough in a small number of tubes to permit efficient tritium counting at room temperature with the simple arrangement of figure 1. Other tubes have high backgrounds that prohibit tritium counting under

any circumstances. A reasonable proportion of photomultipliers, however, lie between these extremes and they may be used for tritium if cooling or coincidence methods are adopted to reduce the thermal background to a suitable level. These techniques result in the so-called single channel and double channel instruments respectively and in both cases phototubes combining low thermal background and high sensitivity are selected as a starting point.

Types of instrument

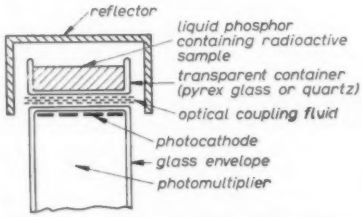
Single channel The system is basically that of figure 1, but the apparatus is cooled to about $-20°C$ to reduce thermal emission from the photocathode. An advantage is that the rate of change of thermal background with temperature is much less at $-20°C$ than at, say, $+18°C$ and so the background is more stable as well as smaller at the reduced temperature. Under conditions yielding counting efficiencies for tritium (defined as counting rate/sample disintegration rate) of 20–30 pc, photomultipliers such as the EMI type 6097 B have backgrounds of about 15–20 cps compared with 200–300 cps at ambient temperature. Little is gained by temperatures lower than $-20°C$ which is easily reached in a simple refrigerator.

Double channel The liquid scintillator is observed by two photomultipliers arranged in a coincidence circuit (see p 595) so that a pulse is recorded only when both tubes observe a scintillation simultaneously. The random thermal pulses, apart from a few chance coincidences, are rejected. The apparatus is sometimes cooled (usually to about 0°C) to improve stability and, at best, yields backgrounds of about 0·3 cps with an efficiency of 20–30 pc for tritium.

Both systems are now available as commercial instruments, the single channel as the Ekco type 612 scintillation counter and the double channel as the *Tri-Carb* liquid scintillation spectrometer made by the Packard Instrument Co in America. With present photomultiplier tubes, the double channel instrument has the superior performance on account of its much lower background but it is a complicated and costly instrument that offers little advantage in the majority of applications over the simple, single channel device. For example, the single channel instrument can measure 10^{-8} curie of tritium in a 1 ml sample to within 2 pc in less than five minutes' counting time. Only extremely low level counting requires a performance better than this.

The method in practice

Figure 2 shows a section of the single channel instrument manufactured by Messrs E. K. Cole. This uses an EMI 13-stage photomultiplier type 9514 S followed by an electronic amplifier with a maximum gain of $\times 1000$. A light-tight shutter between the glass sample container and the photomultiplier window is interlocked with an enveloping lid so that it is impossible to expose the photocathode to extraneous light when samples are being changed. Such an exposure would cause an abrupt increase in the tube background, subsequently needing many hours to return to normal. The shutter unit is a separate assembly with a lower pyrex glass window in contact with the photomultiplier: good optical coupling is made with a layer of silicone fluid MS200 between these two surfaces and the interior of the shutter unit is partially filled with the same medium. To avoid air bubbles, which would reduce the light transmission, the sample container has a slightly convex base.



Here is the basic arrangement for liquid scintillation counting (Fig 1)

The whole assembly is enclosed in a substantial lead screen, the upper part of which is hinged to form a lid, and fits into a metal base holding the electronic amplifier. The complete instrument goes into a small refrigerator and is connected by two cables to external power supplies and a pulse discriminator and counter.

The liquid scintillator normally used contains 3g/litre of 2,5 diphenyl oxazole (PPO) dissolved in toluene. This is stable at $-20°C$ and has a wavelength of maximum emission of 3800 A, which matches the spectral sensitivity peak of the 9514 S phototube very well. With a dynode voltage of about 120 per stage and an amplifier gain of $\times 1000$, tritium may be counted at $-20°C$ with an efficiency, η, of 10–20 pc and a background of 15–20 cps.

For carbon-14 it is necessary to reduce the amplifier gain on account of the greater intensity of the scintillations and this leads to backgrounds of about 0·5 cps with a counting efficiency of 60 pc. Actually, carbon-14 can easily be counted at room temperature with a background of 1–2 cps and an efficiency of approx. 60 pc, and it might therefore seem that it is more advantageous to work at room temperature for this isotope. However, apart from a loss in background stability at the higher temperature, the merit of a counter for weak sources is determined by the expression η^2/R_b where R_b is the background counting rate (*3*) and on this criterion the performance at $-20°C$ is superior especially for very weak samples.

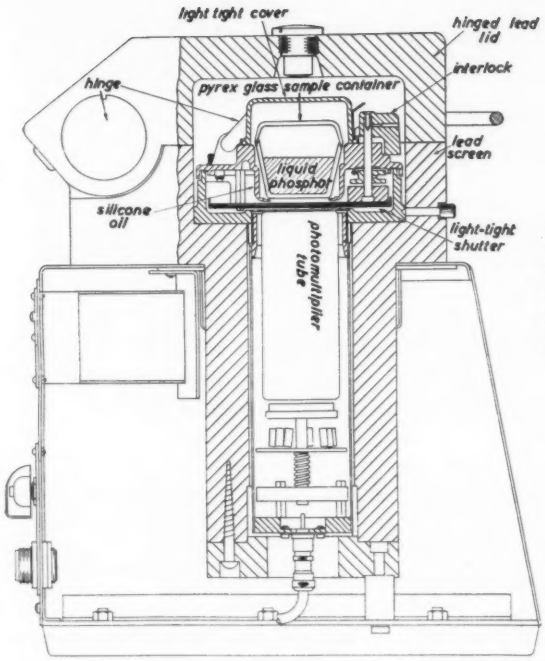
Scintillating solutions

Liquid scintillators and the problems of incorporating radioactive samples form a very large subject (*4, 5*). Simple two-component phosphors such as PPO in toluene are adequate for many purposes and when the sample is soluble in the solvent (toluene) and does not act to quench the scintillations it is usually sufficient to add it to the phosphor. Many compounds among the steroids and fatty acids fulfil these requirements. Some sample materials, however, quench the scintillations in which case the addition of naphthalene as a light restorer is sometimes advantageous. Some samples colour the solutions and the presence of so-called wavelength shifters, such as POPOP, may then be helpful. These absorb the light from the primary solvent and re-emit it at another wavelength which may also match more closely the spectral sensitivity curve of the photomultiplier.

Suspension technique

Insoluble solids may be counted in suspension. The technique is to prevent sedimentation, or to slow it down so that it can be neglected during the counting period, by adding a gelating agent such as thixcin or aluminium stearate. This method, however, causes a slight loss in efficiency due to imperfect light transmission of the gel and the particle size may be sufficient to introduce appreciable self-absorption of low energy betas. An experimental trial with a sample material is always desirable, even if it has previously received unfavourable comment, for so long as total quenching does not occur, the use of an internal standard will often overcome differences in the counting efficiencies of various preparations.

In this technique the sample is counted in the normal way and the measurement then repeated after the addition of a small amount of a non-quenching material labelled with a known concentration of the same beta emitter. The difference of the two counts gives the count due to the standard in the quenching environment and from this the quenching



Cross-section of the Ekco type N612 scintillation counter shows the sample pot in position. Lead-shielded counter is mounted in a steel case containing a five-valve, wide-band linear amplifier (Fig 2)

action of the original sample may be computed and the first measurement corrected accordingly. This internal standard method is, in general, applicable to all problems due to quenching by sample impurities and its use considerably extends the scope of the liquid scintillation technique.

Water is an important sample material since tritium is often presented conveniently in this form. Toluene will dissolve considerable amounts of water in the presence of ethyl alcohol as a blending agent but since water is a quenching agent the least possible volume of a water sample is desirable. Figure 3 shows the variation in counting efficiency for tritium as a function of the water/toluene ratio in a PPO/toluene phosphor. This shows that for accuracy of measurement the water loaded phosphors must be prepared with care and that absolute ethyl alcohol must be used to avoid the introduction of unknown quantities of water.

Applications in tracer work

At present, the liquid counting technique has its principal application to tritium simply because the counting of tritium by any other means is so enormously more difficult. Tritium is cheap and readily available and, as a tracer element, has the additional advantage that there are relatively simple methods of using it to label organic compounds. For example, the gas exposure technique of Wilzbach (6) involves simple exposure of the compound to pure tritium gas at about 1 atmosphere pressure for several days. The energy released in the disintegration of the tritium and absorbed in the system provides the activation necessary to effect labelling. The only other hydrogen isotope is deuterium which is very expensive and, since it is stable, exceedingly difficult to measure on a routine basis.

Liquid scintillation counting thus makes possible for the first time the widespread application of tracer work with hydrogen. The importance of this in the fields of medicine, biochemistry, biology and pharmacology is obviously very great, especially as the same instrument provides a facility for the rapid and convenient measurement of carbon-14.

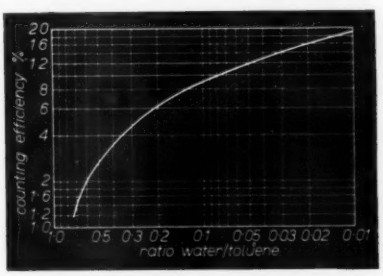
The advantage of tritium is vividly illustrated by its application to the fundamental medical problem of measuring human total body water. Liquid scintillation counting requires a dose of tritiated water costing a few pence and yields an answer within 20 minutes of the measurement specimens becoming available: to use the alternative, deuterium, would cost about £7 per measurement for heavy water and involve a measurement time of several hours. However, the use of tritium is not confined to the biological sciences nor is the liquid scintillation counting technique restricted to tritium and carbon-14. For isotopes emitting beta rays more energetic than those from carbon-14 the method offers a counting efficiency of nearly 100 pc and therefore the instrument provides a rapid and simple means not only of measuring but also of standardizing most beta emitters.

When new techniques and reliable measuring instruments become available, fresh applications, such as the use of tritium in reservoir engineering, tend to follow very quickly.

Future developments

Apart from normal engineering developments in the design of instruments, the greatest advances in performance will come from improved photomultiplier tubes. Already there are signs that the manufacturers are succeeding in producing tubes of much lower thermal background so that for measurements of all but the weakest tritium sources it may soon be possible to use a single channel instrument at room temperature.

This is a controversial subject but, in time, the background of the refrigerated single channel device may approach that now given by a double channel instrument and when this happens its performance may be superior. This is because the single channel instrument counts very weak scintillations more efficiently than does the double: in this latter case there may not be sufficient light to trigger both photomultiplier tubes and the weak scintillations are lost. The merit of the instrument depends on the factor (efficiency)^2/ background and so the



Counting efficiency curve for tritium in a PPO/toluene phosphor shows the critical effect of the quantity of water present (Fig 3)

performance of the single channel device may possibly overtake that of the double before it actually achieves a lower background count.

At the moment, the single channel instrument is certainly to be preferred for its simplicity and lower cost. In future it may be possible to improve the performance of an existing single channel instrument simply by exchanging the photomultiplier.

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PART II

Nuclear powered ships

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Concluding a two-part review of the papers presented at Geneva on ships, this article covers British and Japanese plans and experimental work on the EBWR *and the design of shielding*

A STRIKING CONTRAST in philosophies is presented in the remaining papers on ships. The ultra conservative approach of the two from the United Kingdom adds little to previously stated arguments while the unbounded enthusiasm of the two Japanese papers at times approaches the limit of technical credibility. It is regrettable that there was nothing submitted by the Scandinavian or Low Countries as their confirmation or denial of the French approach, based on cautious optimism, would have been of great value in charting a middle course.

4. Britain's GCR

A complete discussion of the gas-cooled reactor concept for marine application was presented authoritatively by R. V. Moore and C. E. Iliffe of the UK (266). For reasonable comparison with conventional machinery weight plus bunkers carried, a total machinery weight objective of 400 lb/h.p. is recommended. A major factor is the shielding weight and they examine the variation with core size and material density—for instance a 10 ft dia reflector would require 2000 tons of ordinary concrete or 1300 tons of heavy aggregate concrete. No mention is made of metal/water shielding.

Core size is markedly influenced by moderator/fuel ratio which, at 40:1 for graphite, compares unfavourably with water at about 3:1. Economic comparison must include the cost of the respective fuel enrichments necessary and the low enrichment possible in the gas cooled, graphite moderated core is the outstanding factor in its selection. Core size is reduced mainly by subdivision of the fuel to the limit of practical thinness, resulting in increased power rating. Increased gas temperatures giving an enhanced cycle efficiency are also clearly desirable. These trends with suitable fuel cycles are illustrated in table I.

TABLE I—comparison of gas-cooled reactors—Moore and Iliffe

FUEL ELEMENTS	Uranium metal with magnesium alloy cans. 18 rods 0·3 in. dia	Cermet 15 pc wt UO_2 85 pc wt S.S. 14 plates 0·045 in. thick
Cylindrical vessel diameter	18 ft 6 in.	7 ft 4 in.
Cylindrical vessel thickness	3 in.	3 in.
Core diameter	14 ft	4 ft 9 in.
Channel length	13 ft	4 ft 8 in.
Channel pitch	9 in.	7 in.
Gas pressure (psig)	300	800
Inlet gas temperature (°C)	217	260
Outlet gas temperature (°C)	400	480
Maximum fuel element surface temp (°C)	450	600
Irradiation	3000 (MWd/Te)	5 pc wt of UO_2 burnt
Mean fuel rating	11·85 (MW/Te)	0·98 (MW/kg U-235)
Turbine stop valve steam temp (°F)	702	840
Turbine stop valve steam pressure (psia)	500	1030
Shaft horse power	50,000	50,000

FUEL CYCLES	STRAIGHT THROUGH	PU EQUILIBRIUM RECYCLE	
Critical enrichment	1·28 C_o	1·28 C_o	15 pc UO_2 by wt
Fuel enrichment	1·34 C_o	0·885 C_o	17·7 pc ,,
Depleted enrichment	0·96 C_o	0·675 C_o	12·7 pc ,,
Make-up enrichment	—	1·00 C_o	—
Proportion recycled	—	0·354	—

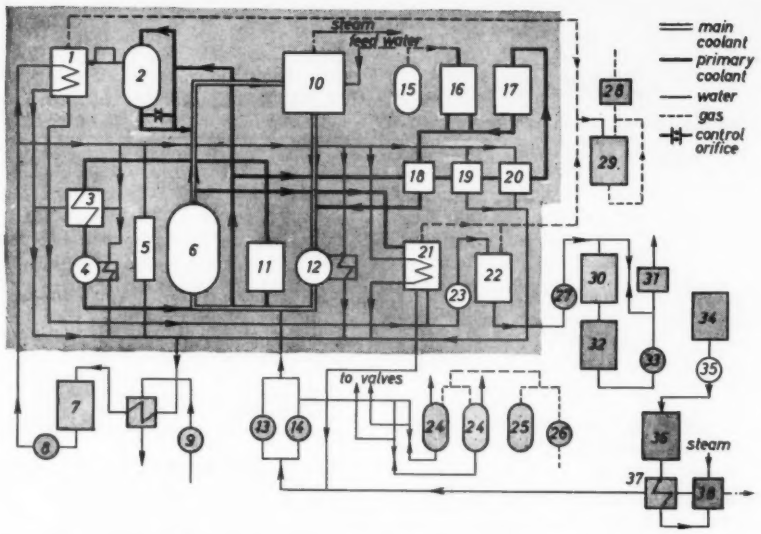
The paper on merchant ships by Smith and Richards (265) consists essentially of the economic aspects of the thesis the authors presented to the Institute of Engineers and Shipbuilders in Scotland in June 1957. They conclude that a maximum enrichment of 1·4 C_o will be acceptable and the possible application limited to ships requiring at least 20,000 shp.

US system too dear

The pressurized water system is as yet alone in the field of proven service, but the capital cost is too high and the cycle efficiency too low for commercial interest. The use of an organic liquid in place of water reduces the system pressure but also the thermal conductivity of the fluid. The capital cost is expected to be reduced, but the evaluation of the system for marine application awaits a satisfactory report on the stability of the hydrocarbon under irradiation and high temperature. American experience reported justifies confidence in this concept. Paper 606 includes a full discussion on marine application and paper 421 provides experimental evidence of technical feasibility.

Gas-cooled systems offer an increased cycle efficiency. Graphite and heavy water moderation is considered, but the former preferred for its less complicated mechanical design. British experience lies mainly within this field, but a minimum attractive power output of 30,000 shp is suggested.

Plutonium should become available from the UK power stations by 1970 and the type of reactor best suited to burning this fuel, while not yet known, may prove to be a liquid moderated system with its negative temperature coefficient.



Flow diagram of Japanese emigrant ship reactor plant shows: 1. blow-off tank 2. pressurizer 3. shut-down cooler 4. shut-down cooling pump 5. shield tank 6. reactor 7. surge tank 8. pump 9. sea water pump 10. steam generator 11. boron mixing tank 12. main coolant pump 13. fill pump 14. charge pump 15. hydrogen cyl 16. hydrogen injection tank 17. demineralizer 18, 19, 20. coolers 21. flash tank 22. waste disposal tank 23. drain pump 24. control water tank 25. HP air cyl 26. HP air compressor 27. waste disposal pump 28. filter 29. waste disposal tank (gas) 30. demineralizer 31. filter 32. waste disposal tank 33. discharge pump 34. fresh water storage tank 35. service pump 36. demineralizer 37. heater 38. deaerator (Fig 7)

5. PWR for Japan

The economic background of Japanese shipping is brought sharply into focus by considering that her total tonnage at the end of 1957 was 4·5 million and that the heavy oil fuel consumption of this fleet approached that of the power generating stations ashore. An annual increase of 300,000 to 400,000 gross tonnage is now called for and all oil fuel must be imported. Japan therefore has an excellent incentive to investigate the alternative offered by nuclear propulsion and a study of her particular trades has shown that the carriage of emigrants to South America is a suitable application. The present annual capacity of ships on this service is 8000 emigrants carried for over 40 days on the one voyage. The aim is to quadruple this capacity and halve the voyage time.

The main characteristics of the vessel proposed (1319) are as follows:

Length overall	205 m
Full load displacement	26,380 tonnes
Deadweight (cargo)	9100 tonnes
Total number of passengers	2500
Number of crew	232
Service speed	23·5 knots
Normal rating	40,000 shp total for 2 screws
Steam conditions	39·6 kg/cm and 250°C
Machinery weights:	
main turbines and condensers	460 tonnes
auxiliary machinery	1140 tonnes
reactor plant	480 tonnes
shield and containment	2320 tonnes

The reactor selected, mainly on the grounds of proven service, is a 180 MW pressurized water reactor which can supply both propulsion and ship service demands. The plant flow diagram is shown in figure 7 and the core was designed to the following specification:

Core life time	10,000 h
Average burnup	9200 MWd/ton UO_2
Core size	160 cm average dia 150 cm high
Geometrical buckling	0·00104 cm^{-2}
Weights: UO_2 fuel	8250 kg
Zircaloy	6300 kg
Volume ratios:	
H_2O/UO_2	1·4
H_2O/U	3·1
Atomic ratios (hot):	
H/U_{235}	2·88
H/U_{235}	167
Enrichment: initial	1·7 atom pc
final	0·9 atom pc
Initial conversion ratio	0·74
Average thermal neutron flux	5×10^{13} n/cm² sec
Pu produced	39·6 kg
k_{eff}: *cold clean*	1·179 max
hot clean	1·122
p	0·791
ϵ	1·05
Coolant pressure	140 kg/cm²
Coolant flow	6800 m³/h
Max velocity through core	4·8 m/sec
Pressure drop across core	1·58 kg/cm²
Coolant temperatures:	
inlet	259°C
outlet	281°C
Max fuel temperature	1490°C
Heat transfer area	412 m²

From this specification emerged a core configuration built up from UO_2 pellets 9 mm dia and 9 mm long. 54 of these pellets are stacked inside each Zircaloy tube 10·25 mm o.d. and 0·6 mm wall, to form a fuel rod 50 cm long. The rods are located in bundles of 100 spaced at 13 mm pitch. Three of these bundles, end to end, form an assembly and there are 88 such assemblies.

A unit containment vessel is to be used to enclose the components of the primary circuit indicated in figure 7. It is designed to withstand an internal pressure of 12 kg/cm² on similar maxims to those used in the *Savannah* design but in addition is lead lined to assist in both secondary shielding and missile containment. The primary shield consists of water filled tanks, polyethylene and lead; hot spots such as the reactor outlets, steam generators and demineralizers, are locally shielded with lead.

Secondary shielding surrounding the containment vessel consists of structural steel and heavy concrete which determines the following permissible exposures in a rem/h and associated exposure limits in h/day: passenger and crew accommodation 0·17 (24); machinery compartments 0·53 (8); store-rooms and cargo holds 1·43 (3).

A detailed economic analysis is made for the building and operation of this vessel. The construction cost for hull and machinery is the equivalent Yen value of $M24 US and the fuel cost, based on USAEC price quotations for enriched fuel and plutonium credit, is the Yen equivalent of $M2·489 per core.

Submarine oil tanker

The novel feature of the nuclear powered submarine tanker (1320) lies mainly in a hull design exploiting the elimination of wave making resistance by submerged navigation. Crude oil is the cargo selected for its amenability in reducing problems such as stability by weight distribution and the ease of handling without unduly affecting the pressure tightness of compartments. The maximum size of submarine is dictated by the optimum surface (skin friction effect), considering the economic use of both hull steel and reactor power (figure 8).

Fortunately the power requirement is met by the machinery specification for the emigrant ship described in Paper 1319. The two power plants are consequently identical, with the exception of cargo handling which is dealt with by three 1000 m³/h and two 350 m³/h centrifugal, steam turbine driven pumps. These also provide for rapid ballasting in the light ship condition.

The pressure resisting hull, to withstand submersion safely to a depth of 100 metres, is confined to the inner skin which is divided into three main compartments:

1. A forward section, of spectacle frame shape section, including the accommodation space, control

room, auxiliary machinery room and four cargo oil tanks

2. A midship compartment of cylindrical form which comprises both the reactor containment and secondary shielding

3. An aft compartment which consists of a spectacle frame shape section engine room tapering to cylindrical form for the pump room and four cargo oil tanks.

The outer hull is sub-divided by transverse and longitudinal watertight bulkheads to form 30 cargo oil tanks and 10 main ballast tanks. The hull equipment provides piping and pumping facilities for oil and water ballast, bow and stern diving gear, life saving gear including escape hatches, radiation shielding and health control, and a disposal system for raidoactive waste.

6. Developments

Experimental evidence of interest to the marine industry was presented in voluminous proportions at Geneva but space precludes mention of all but two of these papers. The light water boiling reactor system has now demonstrated such favourable performance that details of the operational stability and activation of the turbine circuit warrant inclusion. Shielding has to date been unpardonably neglected in the published literature. The United Kingdom work on metal-water shields is therefore reviewed since it is particularly pertinent to mobile reactors.

The most important engineering achievements demonstrate that the natural circulation boiling system is capable of high heat density operation (2379). Operational reliability at power was proved with EBWR since no non-scheduled shut-down occurred during operation throughout 1957. Shut-down circuits proved to be very practical. Satisfactory stability was thus achieved and the investigations established the following criteria:

1. Absolute gain and phase margins can be predicted by experiment on a specific reactor

2. Stability can be estimated for a new design by the application of the principles of feedback analysis

3. A very large increase in the time constant of heat transfer associated with fuel will improve stability

4. The amount of reactivity in voids is not a singular criterion of stability

5. Incremental changes in void reactivity with power is an important stability consideration

6. The magnitude of noise in the boiling reactor flux signal is not simply related to ultimate stability

7. Xenon history and flux shape have a definite effect on absolute stability

8. In final analysis of stability, void flux flattening, in conjunction with radial void coefficient effects, can be important.

The surface activities in mr/h established during the operation of EBWR are shown in Table 2. The principal constituent of this activity is 7·4 sec half life N-16. Following one year's operation, the current components were opened up and the following activities measured:

TABLE II—Surface activities in EBWR during operation (mr/h)

REACTOR POWER (THERMAL)	10 MW	20 MW	40 MW	67·7 MW
Air ejector after cooler	90	400	4000	7000
Condenser hot well	10	40	240	580
Steam drier	80	150	600	720
Turbine exhaust casing	2	4	14	20
Feed water filters	8	10	50	100
Plant air exhaust	6	12	40	120

a. Steam drier—5 to 6 mr/h, mainly from iron oxide coating

b. Turbine casing 10 days after shut-down—5 mr/h at the nozzle inlets and 0·2 mr/h at the blades

c. Condenser hot well—less than 2 mr/h.

A bleed filter and ion exchange system is fitted in duplicate and the vessels shielded by 4 in. lead. In operation the activity builds up to 1 r/h and 10 r/h respectively inside these vessels, but a two-week decay period is sufficient to avoid transporting used filters and resin columns ashore inside the shield.

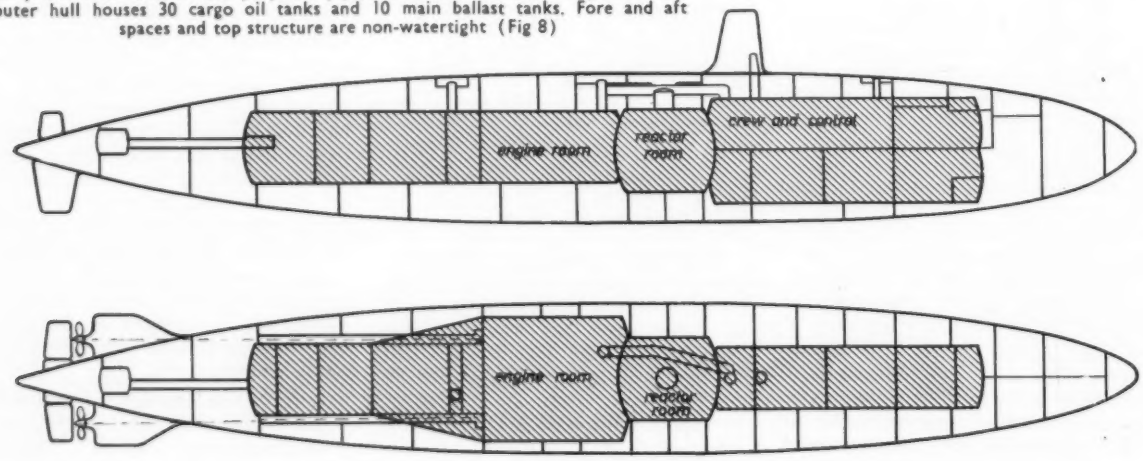
These activity levels demonstrate that access for routine maintenance of the turbine plant need not be unduly restricted and local shielding of moderate proportions should provide adequate protection during operation.

Shielding design

A major requirement in reactor shield design is the accurate prediction of the spatial distribution of thermal and epithermal flux, primarily to enable the generation of capture gamma rays to be calculated. This requirement is particularly important in shield systems consisting of multiple layers of metal and water for which the available theoretical methods of prediction are either inapplicable or excessively cumbersome to apply.

The detailed distributions of thermal flux have been investigated in the

Only the inner skin of the proposed Japanese submarine tanker is pressurized; outer hull houses 30 cargo oil tanks and 10 main ballast tanks. Fore and aft spaces and top structure are non-watertight (Fig 8)



UK for a series of multilayered systems of iron and water and the experimental data interpreted on the basis of a three group model (84/Rev 1). This model describes the three basic features of neutron behaviour in shields: the flight of virtually uncollided neutrons, described in the model by 'removal' theory; the slowing down of neutrons subsequent to scattering out of the uncollided group, dealing separately with the neutrons scattered within the layer considered and those originating externally from leakage etc; and the diffusion of neutrons at thermal energies. For an adequate interpretation of the data on the basis of this model it was necessary to obtain some of the three group parameters empirically for iron and water.

Bulk shielding experimental tank in Lido was used for determining the flux distribution in a series of multilayered systems of iron and water (Fig 9)

Work at Harwell

The three group model described provides a prediction of the thermal flux, generally to an accuracy better than 20 pc, and the epithermal flux; ease of application to complex multilayered systems is achieved at the expense of using empirical parameters. This treatment is amenable to programming on a high speed digital computer and a programme is available to deal with up to fourteen regions in plane or cylindrical geometry. Thus a particular shield configuration can be optimized in design within a reasonable time.

The experimental equipment used is shown in Figure 9 using the Harwell reactor Lido as neutron source. The experimental array of steel slabs can be seen set in the tank, the positional accuracy of which is better than 1mm. Neutron flux measurements were made within the slabs by activation of manganese and indium foils and in the surrounding water by B-10F_3 proportional counters and U-235 fission chambers, carried on the quadrant arms which can be positioned within 1 mm in each direction.

7. What now?

Main interest evidently centres on the selection of a reactor system best suited for commercial marine use. This specification is too broad to single out any one system and the choice must be influenced by conditions applicable to a particular country's shipbuilding capacity, trade requirements and the economics affecting fuel supply. However, the proven service of the pressurized water reactor for submarine use has already inspired two commercial ship applications which will be in service within the next two years.

Two variations, the organic liquid and boiling light water systems, show distinct promise of improved performance attainable within say the next five years. The case made at Geneva for the latter system is particularly attractive. Advantages now claimed are the relatively low primary system pressure and containment pressure and the very low activation of the turbine circuit, all of which should be reflected in construction costs and safety features. Full scale tests on EBWR have demonstrated stable operation and low activation of the turbines following one year's operation on a direct cycle. The French have cautiously specified an intermediate heat exchanger. Their calculations show that stability need not be unduly affected, even under conditions aggravated by ship motion. Low steam conditions have to date been associated with water systems, but the Allis Chalmers proposal for a controlled recirculation boiling reactor with nuclear superheat should obviate this limitation. Steam will be produced at 525 psi and 825°F and used for power generation in 1962.

Enrichment cannot be divorced from compactness and it could well be that the use of plutonium will highlight the advantage of the negative temperature coefficient of a liquid moderated system. No doubt these and other arguments prompted the decision—mentioned by Sir John Cockcroft in his closing summary of the conference — that the United States expect to build a nuclear tanker using a boiling water reactor for propulsion by 1962.

Three years ago the high temperature gas cooled reactor directly coupled to a closed cycle turbine was proposed in a paper to the Institute of Marine Engineers. As a longer term objective, attainable within say ten to fifteen years, this possibility is still valid. The French study now supports the case and the US Maritime Administration project, now under contract with the General Dynamics Corporation, to demonstrate the operation of a prototype within the next seven years, may well prove it.

Code of practice needed

An early formulation of a code of construction and operational practice was called for by several well informed speakers during the discussion of the papers. At national level, the Minister of Transport has invited interested parties to be represented on a committee to advise on the safety of nuclear ships at sea and in port. All authors of the ship papers emphasize the paramount importance of the safety features of their respective designs. More detailed consideration was given in many other papers to such subjects as containment and the disposal of active waste. Paper 2352 is particularly recommended for the discussion of the legal problems of liability and financial protection covering the laws of many countries. The British Government has proposed to all governments contracting to the International Convention for the Safety of Life at Sea that these matters be tabled in 1960.

The opinions expressed are those of the author and do not necessarily reflect the official views of the Yarrow Admiralty Research Department.

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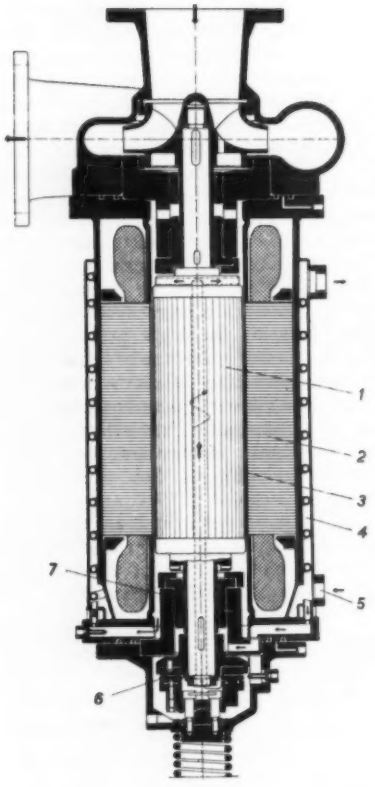
Circulation of reactor coolants calls for machines with high sealing standards and radioactivity protection. Here are some problems which faced Sulzer engineers

by R. A. STRUB, Dipl. Ing. E.T.H.

Chief Engineer, Rotary Machinery, Sulzer Brothers Ltd

Designing pumps and blowers for nuclear power plants



This lightweight heavy-water pump with canned motor is used in the 10 MW reactor at Würlingen, Switzerland. Details are: 1. Rotor 2. Stator 3. Casing 4. Heat exchanger 5. Cooling water 6. Axial bearing 7. Radial bearing (Fig 1)

THE CONSTRUCTION of turbomachines for use in nuclear plants presents the designer with new problems and at the same time renders more difficult the solution of problems with which he is already familiar, since numerous limitations are imposed upon design. The turbomachines must withstand the effects of temperature, corrosion and radiation, and must offer every guarantee in respect of hermetic sealing. The avoidance of contamination by harmful substances such as oil, or the exclusion of humidity from the atmosphere, raises the problems of dry friction of moving parts, of virtually absolute gastightness, and of the treatment and de-gassing of surfaces. The machines must furthermore offer a maximum of operational reliability with a minimum of maintenance, which must be as simple and straightforward as possible.

As the machines must often work under completely new conditions, extensive laboratory tests are necessary in order to ascertain the effects of all the factors involved, whether they act singly or simultaneously.

Limitations in design

The dimensions of a pump or an axial or radial compressor are influenced by a number of factors. With

Table 1 Influence of type of gas on the performance of a radial compressor

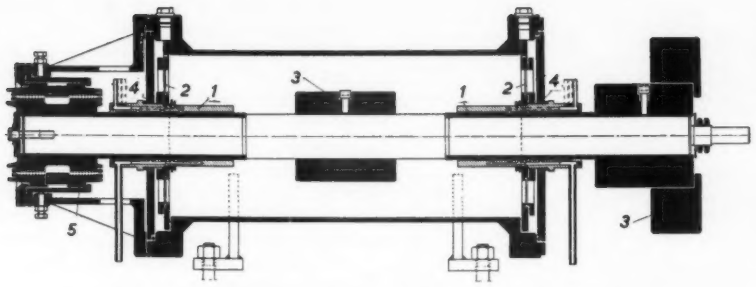
GAS	M	σ/σ_0	U/U	p_2/p_1	Q/Q_0	
UF_6	0·90*	0·14	0·37	7·5	0·21	
Freon 12 (CF_2Cl_2)	0·90*	0·42	0·65	7·5	0·37	
CO_2	0·90*	1·0*	1·0	5·0	1·0	steel rotor
N_2	0·70	1·0*	1·0	3·0	1·0	
He	0·28	1·0*	1·0	1·2	1·2	
He_2	0·21	1·0*	1·0	1·1	1·2	
He	0·42	1·35*	1·5	1·5	1·8	titanium
H_2	0·32	1·35*	1·5	1·25	1·8	alloy rotor

Temperature at machine inlet = 3530 U° = 450 m/s M = Mach number σ = stress p_1/p_2 = pressure ratio Q/Q_0 = volume of gas aspirated * = limiting values U° = peripheral speed

Table 2 Influence of type of gas on an axial compressor

GAS	M	σ/σ_0	U/U	p_2/p_1	Q/Q_0	
UF_6	0·9*	0·06	0·25	3·8	0·25	
Freon 12 (CF_2Cl_2)	0·9*	0·2	0·45	4·2	0·45	
CO_2	0·9*	0·6	0·77	4·3	0·75	steel rotor
N_2	0·9*	1·0	1·0	4·5	1·0	
He	0·45	2·2*	1·5	1·9	1·5	
He_2	0·35	2·2*	1·5	1·4	1·5	
He	0·7	3·0*	2·3	3·8	2·3	titanium
H_2	0·55	3·0*	2·3	2·1	2·3	alloy rotor

Number of stages = 10 U° = 210 m/s at rotor



Using this test rig, gas-lubricated, radial bearings have been tested at speeds up to 12,000 rpm. Drawing shows : 1. Gas-lubricated bearing 2. Flexible supports 3. Rotors 4. Seals for tests under partial vacuum 5. Axial bearing (Fig 2)

a pump, for instance, the peripheral speed at the shaft seal or at bearings immersed in the delivery medium, or in other cases the suction head (cavitation), may be determining factors in the choice of speed, which in its turn fixes the diameter of the pump. The number of factors which limit the choice of dimensions in a gas compressor is even greater.

Knowledge of these limits is necessary to enable the designer to reduce the dimensions of the machine—and therefore the internal surface area and volume—as much as possible, which is particularly important when an expensive medium is to be pumped or gas elimination from the surfaces is necessary.

The speed of sound for heavy gases, such as uranium hexafluoride or Freon 12, is relatively low. It follows that at high pressure ratios the peripheral speed at the inlet to the machine may be fixed by the Mach number. On the other hand, for light gases, such as hydrogen and helium, the tensile strength of the material used for the rotor will be the limiting factor.

Radial and axial compressors

First consider a single-stage radial compressor with open impeller which is used for compressing light or heavy gases, and the diameter of which we may take for reference purposes as unity. We assume that the peripheral speed does not exceed the limit set by the maximum permissible stress in the rotor, and that the Mach number at the inlet diameter of the impeller is limited to the maximum value of 0·9. From these given values the other characteristics of the machine may be determined, i.e. discharge rate and pressure ratio. All data relating to nitrogen will be regarded as reference values with which those for other gases may be compared. As soon as a value reaches the prescribed limit it will be marked with an asterisk, for it is such values that restrict the speed of the rotor and thereby determine the size of the machine.

Table I shows that in the case of the heavy gases in question it is the maximum Mach number at the impeller inlet which limits the number of revolutions. With uranium hexafluoride (UF_6), however, the low ratio of the specific heats (1·06) and the high pressure ratio of 7·5 results in a relatively small volume of gas at the outlet. The ratio between the width of the impeller at the outlet and the outside diameter is therefore 2·2 pc, which is regarded as the lower limit. With CO_2 the strength limit of the rotor is reached almost at the same time as the specified Mach number. In the case of N_2 and the light gases, the limit is determined solely by the strength of the rotor.

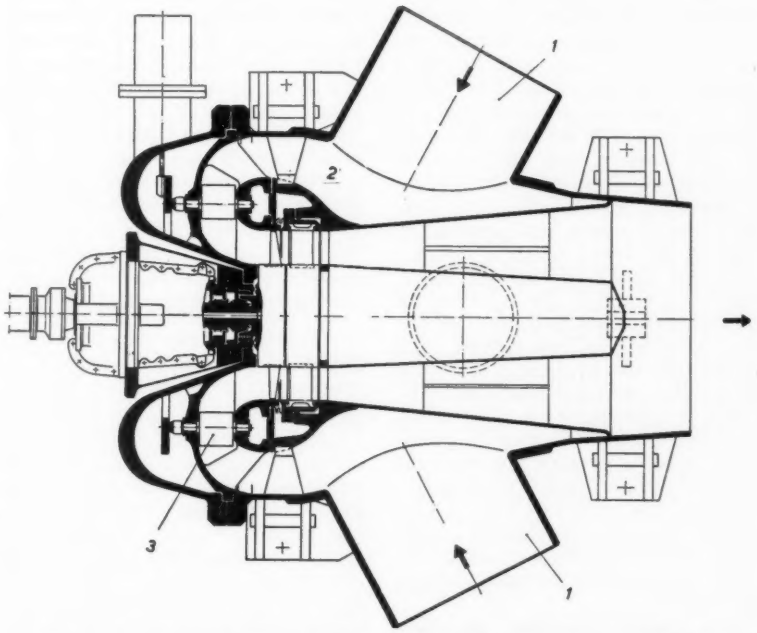
If materials are used for which the ratio σ/ρ (permissible stress/specific mass) assumes a progressively smaller value, it will be clear that the limit based on the strength of the impeller will be displaced towards 700 m/s for the light gases, as can be seen from the last two figures in Table 1.

A similar comparison can be made with axial compressors. Table 2 gives details of results obtained with a ten-stage compressor having a radius ratio at the inlet of 1·5. The Mach number at the blade tip at the inlet was limited to 0·9.

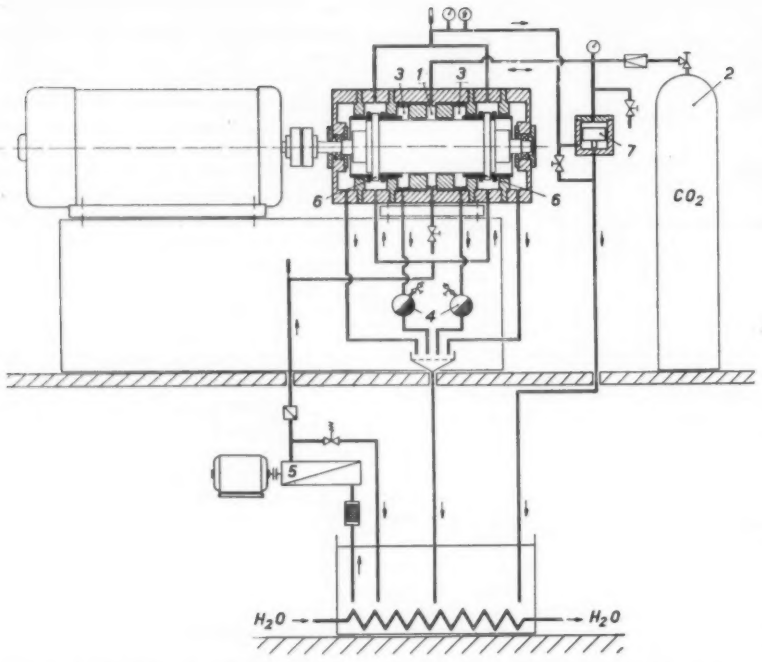
It is interesting to note that it is the Mach number which limits the peripheral speed of the rotor for the first four gases, whilst with the light gases the maximum number of revolutions of the machine depends on the strength of the material. Here also materials with a more favourable σ/ρ ratio can be used to advantage in order to raise the pressure ratio or reduce the number of stages.

Circulation pumps

The pumping of dangerous or very expensive media poses the problem of absolute sealing. As no movable seal can be guaranteed absolutely leak-proof, a pump set must be devised in which the rotor of the electric motor is enclosed in a hermetically sealed casing. Pumps of this type with canned motors have been available for some years. The essential characteristics of these pumps is that their bearings are



Primary CO_2 blower for France's EDF-I at Chinon has power input of 9000 kW, runs at 2950 rpm. 1. Gas inlets 2. Annular chamber 3. Adjustable inlet guide vanes (Fig 3)



In one of various shaft sealing principles tested for the EDF-I blower the balancing of the gas forces was obtained by two opposed seals, tested simultaneously. Details of rig shown are: 1. Space representing machine casing 2. Sealing-gas bottle 3. Spaces for collecting oil and sealing gas 4. Oil separators 5. Sealing-oil pump 6. Seals 7. Pressure regulator for sealing oil (Fig 4)

lubricated by the medium being pumped, whether it be gas or liquid. Sulzer Brothers have carried out several tests in order to ascertain the limiting loads of these bearings as a function of temperature and speed.

Figure 1 shows a section through one of the pumps with fully enclosed motors used for circulating heavy water in the Swiss reactor plant at Würenlingen. This unit was developed in collaboration with the Sécheron company of Geneva. Of very light construction, it is adapted to the relatively low pressure and temperature level of the heavy water. The motor is cooled partly by ordinary water, which flows around the stator casing in a cooling jacket, and partly by the circulation of the heavy water in a heat exchanger arranged in the form of a coil round the motor. The heavy water is circulated by a small pump fitted on the main shaft of the machine. The stator windings are immersed in a substance which facilitates removal of the heat. The flanges have double seals, and any leakage can be easily checked by means of a leak detector connected to the space between the two seals.

The design principles described above can be applied, with certain modifications, even at much greater pressures and temperatures.

Increasingly stringent safety regulations often require the placing of the motor-compressor set in the gas flow. The gas-lubricated axial or radial bearings naturally form a very important component of such a totally enclosed unit. Figure 2 shows a test rig for investigating the behaviour of radial bearings under load and at different pressures. Knowledge of this last variable is important as the admissible specific load varies considerably with the absolute pressure. Numerous tests have been undertaken, at speeds up to 12,000 rpm, to study the behaviour of rotors supported in gas-lubricated bearings during the starting and stopping periods.

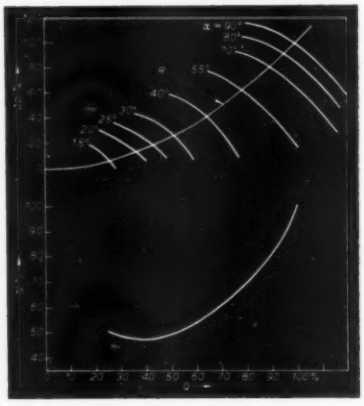
EDF-1 axial blower

The blower to be used in the primary CO_2 circuit of EDF-1 is shown in section in Figure 3. The gas enters the compressor at a temperature of 140°C and a pressure of 26 kg/sq cm abs (370 psi) through two lateral suction branches 1 and is distributed in an annular chamber 2 before flowing through the adjustable inlet guide vanes 3 which regulate the discharge. The machine runs at a constant speed of 2950 rpm and delivers 1600 kg (2275 lb) of CO_2 per second at a pressure ratio of about 1·06. The power input is about 9000 kW under normal working conditions.

The design of a machine of this nature with an outside diameter of about 10 ft naturally poses a number of problems in fixed and moving seals and the dry friction of the moving parts inside the machine for controlling the guide vanes. A special device enables the bearings and shaft seals to be inspected or changed while the machine is under a pressure of 26 atmospheres.

Shaft seals

Various designs of shaft seals have been made the object of exhaustive investigation. One of the sealing principles adopted is shown in Figure 4, which is a schematic drawing of the test rig. The balancing of the gas forces is obtained by two opposed seals which were tested simultaneously. Many designs have been developed with the aim of eliminating the instabilities which occur with balanced mechanical seals operating under high differential pressures. Space 1 corresponds to the housing of the machine, which must be kept free of all oil contamination. A small quantity of sealing gas can be introduced into it from the storage bottle



Under test the machine shown in Fig 4 gave these results. Here Δp = pressure generated N = power input Q = discharge α = angular setting of adjustable guide vanes R = circuit resistance (Fig 5)

2. Any leakage oil is collected in space 3 and conducted to the oil separators 4 together with the sealing gas. The sealing oil delivered by pump 5 is led into the seal chamber 6 at a pressure which is maintained by regulator 7 at a higher level than that of the sealing gas.

The characteristic of the machine over its range of control is plotted in Figure 5. This discharge is regulated at constant speed by means of the adjustable guide vanes.

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Scaling and coincidence circuits

Fundamental to experimental nuclear physics, these circuits are also important in applying isotope techniques to research and industry. Here is an introduction to their operating principle and uses

COUNTING CIRCUITS

Scaling units are used to count and record the number of voltage pulses produced by a radiation detector or by associated equipment such as a scaling unit. In the conventional form, which has been in use for the last ten years, scaling units consist of an electronic scale of one hundred and a mechanical register. The mechanical register, which should reset to zero, records the hundreds while the units and tens are displayed by neon lamps.

As the time intervals between pulses from a radiation detector are randomly spaced in time, the scale of one hundred, preceding the mechanical register, has an important function. Not only does it reduce the counting rate, but it has a strong regularizing action so that the pulses counted by the mechanical register are almost equally spaced. It is possible therefore to allow the mechanical register to count pulses at rates near the maximum set by the manufacturer, without the possibility of counts being lost.

The number of pulses to be recorded, and the rate at which they arrive at the scaler input, vary enormously. For example, in the assay of tritium using a scintillation counter or in the C-14 archaeological dating method, the counting rate is of the order of a few counts per minute. Alternatively the counting rate may be of the order of several million pulses per minute in experiments with the intense beams of particles produced by accelerating machines .

When considering whether a scaling unit is suitable for counting at a given rate it is necessary to know the value of a parameter which is called the 'dead time,' defined as the minimum time which must elapse after a pulse before another one can be counted. A pulse which occurs during the dead time will be missed and this time is therefore important in calculating the fraction of incoming pulses which is registered by a scaler. It is important to know that pulses from a radiation detector occur at randomly spaced time intervals. Suppose for example that a radiation detector produces pulses at a mean rate of 10^4 pulses per second. Although the average time interval between pulses is 100 microseconds, many pulses occur at time separations which are much shorter than this, and a scaler with a dead time of less than 100 microseconds would be necessary to avoid losing a significant number of counts.

If the mean counting rate is N pulses per second and the scaler dead time is τ seconds then the percentage of pulses counted is given by the formula:

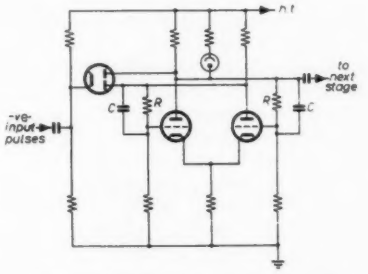
$$\frac{\text{recorded counting rate}}{\text{true counting rate}} = \frac{100}{1 + N\tau}$$

Hence a scaler with a dead time of 5 microseconds would be required to count pulses at a rate of 10^4 cps with 5 pc losses.

Conventional scalers

The principle of the conventional scaler has been described above. The scale of one hundred, which precedes the mechanical register, is based on the scale-of-two circuit shown in figure 1. The two thermionic valve triodes are symmetrically cross-connected and the anode potential of one determines the grid potential of the other. If one valve is passing current, the d.c. levels are arranged so that the grid potential of the other is sufficiently negative, with respect to its cathode, to prevent the flow of anode current. Each negative pulse applied to the input terminal causes the circuit to change its state. It is possible to connect several of these circuits in series so that the first circuit changes its state every time an input pulse is applied, the second circuit changes its state at every second pulse and so on. Scaling factors of 128 are quite usual. A scale of sixteen, consisting of four scales of two, may be converted into a scale of ten by a simple modification. Two such scales of ten are used in the conventional scaler to give a scale of one hundred.

There are several reasons why the



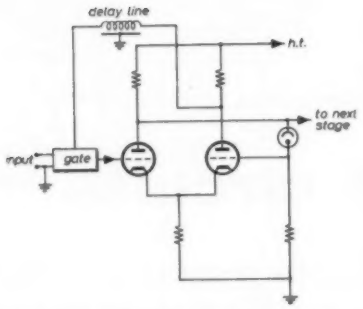
The scale-of-two circuit forms the basis of a conventional scaler (Fig 1)

conventional scaling circuit is not completely satisfactory. The circuitry is complicated, which makes servicing difficult, and it tends to be unreliable because of the heat dissipation. The conventional scaler usually has a dead time of the order of a few microseconds and for many purposes this is unnecessarily short and occasionally too long.

Many attempts have been made to produce scaling units which answer these criticisms. Some of these circuits are discussed below.

Fast circuits

Faster circuits are required not only for high speed particle counting but in many other electronic circuits used in the nuclear field. For example, fast scaling is used in high frequency



Fast scale-of-two circuit uses a delay line for memory (Fig 2)

meters and time interval analysers.

The speed of operation of the conventional scale of two circuits, shown in figure 1, may be increased by the use of peaking coils, clamping diodes and coupling cathode followers. These circuits require close tolerance design and may be rather complicated. If secondary emitting pentodes are used, a very fast scaling circuit is possible but there is difficulty in stabilizing the quiescent current in it.

However, the principal difficulty in achieving high speed operation is that of obtaining reliable triggering. In order to achieve this it is necessary to make the value of the time constant CR (figure 1) larger than the value needed to make the resistance network frequency independent. This time constant acts as a memory of the previous history of the circuit and helps to achieve a positive triggering action. However, if a scale of two is designed for fast operation then the value of C must be reduced in order to keep the anode capacity small. Thus high speed operation and reliable triggering are mutually exclusive and it is difficult to reduce the dead time below a few tenths of a microsecond.

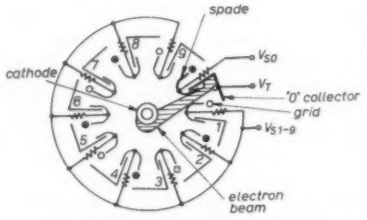
The circuit shown in figure 2 uses a delay line to provide a memory of the previous history; the functions of memory and switching action are located in separate parts of the circuit. The scale of two consists of a cathode-coupled flip-flop circuit. The bias is arranged so that the circuit has two stable states and pulses of alternate sign—provided by the gate—are required at the left-hand control grid to change from one to the other. The polarity of the pulse from the gate is decided by the state of the scale of two to which it is d.c. connected. If the input pulses to the gate have a duration which is shorter than the delay line, the gate is switched after an input pulse and after the scale of two has reached its new state. The triggering action is thus quite positive.

Scaling circuits using this principle have been constructed which are capable of recording pulses separated by 40 millimicroseconds. It is found that the triggering action is more reliable than that of conventional circuits.

Trochotron scalers

The trochotron valve, which is a decimal counting tube, has undergone considerable modification since its invention by Alfven. In the form developed by the Haydu Company it may be used in a scale-of-ten circuit with a resolving time of 0·1 microseconds and with a minimum of associated circuitry.

The operation of a trochotron uses the principle that a low energy electron beam travelling in mutually perpendicular electric and magnetic fields will execute a trochoidal path between equipotential lines. The geometry is shown in figure 3, in which an axial cathode emits electrons towards a ring



Trochotron valve provides a compact scale of ten (Fig 3)

of collectiong electrodes. Inside the collectors there is a further ring of equally spaced electrodes called spades. An external cylindrical magnet provides an axial field. When the collectors and spades are at some positive potential with respect to the cathode no current across the valve is possible. If, however, the potential of one spade is reduced to cathode level, current will flow in the region of that spade and collector and the path of the electrons will be as shown in figure 3. In such a situation about 90 pc of the beam falls on a collector and almost 10 pc on the spade. Resistances are connected between the spades and the H.T. supply. If a beam is formed in the vicinity of a spade, a current will flow in the resistance, lowering its potential, and the necessary conditions for a stable beam will be established at that spade. The beam is stable in any one of the ten positions and transfer from one position to the next is brought about by changing the potential of further electrodes called 'grids,' located between the spades.

The trochotron provides a compact scale-of-ten as only two driving valves are necessary to effect the transfer of the beam from one position to the next. It is claimed by the manufacturer that the switching action is not critically dependent on the stage of the cathode and that a long operating life may be expected. Scales of one hundred have been constructed with two trochotrons and a dead time of 0·1 secs.

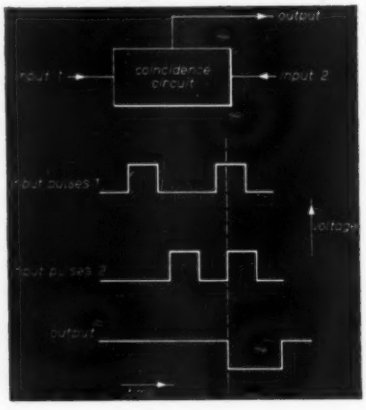
In spite of these attractions, however, it is not likely that trochotrons will be extensively used in scaling units as their development will probably be overshadowed by semiconductor devices.

Dekatron scalers

In many scalers the circuitry is based on the use of gas discharge tubes. A typical example is the dekatron decimal scaling tube in which a glow discharge is transferred round a series of ten electrodes. The anode is a disk round which thirty wires are symmetrically placed. This electrode structure is mounted in a glass envelope and the gas pressure adjusted so that a glow discharge is possible between any wire and the edge of the disk. In use it is arranged that the glow, which is visible through the glass envelope, takes place between any third wire and the anode. These are the ten stable positions used and the glow is transferred from one position to the next by manipulating the potentials of the intervening wires or 'guides.'

The circuitry required to bring about the movement of the discharge is not complicated, and five tubes, connected in series, form a convenient scaler with a resolving time of 300 microseconds and a capacity of 10^5 counts. No mechanical register is necessary. As the current in the glow discharge is small, the power dissipated is less than in the hard valve scales, with a consequent improvement in reliability.

For output to be generated in coincidence circuit, pulse must be present at both input terminals (Fig 4)

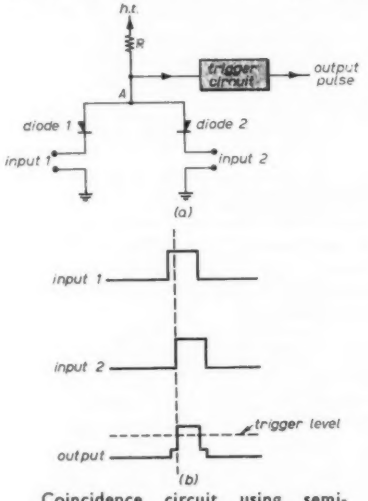


COINCIDENCE CIRCUITS

The purpose of a coincidence circuit is to determine whether two or more events occur within a specified time of each other: an 'event' usually means the detection of a nuclear particle by a scintillation counter.

The action of a coincidence circuit is shown in figure 4. A pulse must be present at both input terminals for an output pulse to be generated: this is obtained if one leading edge of an input pulse occurs within a time T of the other. T is called the 'coincidence resolving time,' and its value may lie in the range 10^{-9} to one second. A coincidence circuit may require the simultaneous application of several input pulses in order to produce an output pulse and such 'fivefold' circuits are in common use.

Figure 5a shows a coincidence circuit using semi-conductor diodes D_1 and D_2. The relevant voltage waveforms are shown in figure 5b. Positive pulses, standardized in height and

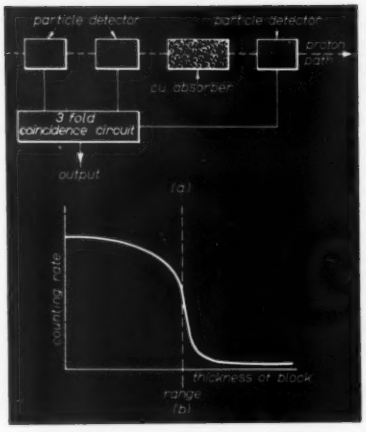


Coincidence circuit using semi-conductor diodes produces the waveform shown (Fig 5)

duration, are applied to the two input terminals. If a pulse occurs at input 1 only, the diode D_1 ceases to pass current and the potential at A rises until diode D_2 carries all the current through the resistance R. The potential at A rises by a few tenths of a volt only and the trigger circuit does not fire and there is no output pulse. If two input pulses coincide in time both diodes will be cut off and the potential at A will rise to the height of the input pulses. The trigger circuit will then produce an output pulse.

Application to isotopes

It is often necessary to measure the distance a particle will travel in some material before coming to rest. A



Coincidence circuits may be used for measuring range of nuclear particles in materials (Fig 6)

method of making such a range measurement is illustrated in figure 6a. A typical example might be the problem of finding the range of 300 MeV protons in copper.

The line of the three particle detectors defines the path of the protons through the copper block and constitutes a 'counter telescope.' A particle must pass through the three counters, connected in coincidence, and therefore through the copper block, before an output pulse is obtained. Should a particle not pass through the third detector an output pulse is not generated. A graph of counting rate, plotted against the length of the path of the particle in copper, is shown in figure 6b and from it the particle range may be obtained.

A typical arrangement for measuring short lifetime is shown in figure 7. An isotope of this class is neptunium-237 which has an excited state. This nucleus is formed when americium-241 emits an alpha particle and then subsequently the neptunium-237 emits a gamma ray to become a stable nucleus.. Thus by measuring the time between the alpha and gamma emission the lifetime of the excited state of the nucleus may be determined.

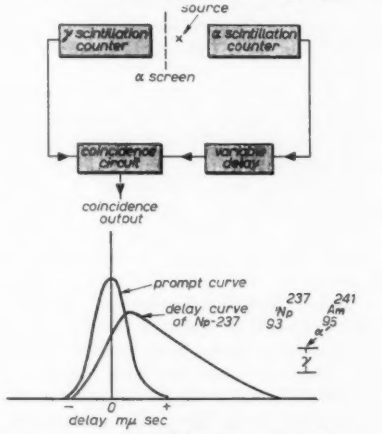
Referring to figure 7 the alpha particles are detected by a scintillation counter and the gammas are similarly detected but through a thin screen to remove the alphas. The output rate of the coincidence unit is then measured for different values of the delay introduced in series with the alpha counter. This delay will bring the pulses from this counter into time coincidence with the gamma rays. The curve obtained is shown in figure 7 showing that some of the alphas are delayed with respect to the gammas. A similar curve is then plotted for a source having negligible time between the emission of two particles, and this is shown as the prompt curve in figure 7. By suitable analysis of these curves the average lifetime of the nucleus under investigation may be determined. The value for the particular case under consideration was about 9 millimicroseconds.

Resolving time

Experiments are often performed in which coincidence rates are measured in the presence of a large background of radiation. For example, measurements are made on beams of particles from accelerating machines using counter telescopes. It is the purpose of the telescope and coincidence circuits to distinguish the 'genuine coincidences,' indicating a wanted particle, from 'random coincidences,' which are due to the accidental passage of different particles through the counters. It is important to be able to calculate the random coincidence rate due to the accidental coincidence of otherwise unrelated events.

Suppose that two counters registering counting rates N_1 and N_2 are connected to a coincidence circuit of resolving time T. During one second, channel 1 will be operated for a total time N_1T. But during this time, $2N_1N_2T$ counts will occur in channel 2. Hence the random coincidence counting rate is $2N_1N_2T$.

The formula $N_R = 2N_1N_2T$ pro-



Short isotope lifetimes may be measured by this arrangement (Fig 7)

vides a convenient way of measuring the resolving time of a coincidence circuit. Two independent sources of radiation must be used to provide the two inputs required. The values of N_1, N_2 and N_R are measured over a given period of time and T calculated.

It is clear that this formula is used in deciding the resolving time necessary in an experiment. Further, if a correction is to be applied for the random rate, then it will be necessary to make sure that the value of T is stable.

Some design considerations in gas cooled reactors

by H. WEST and A. L. SHAW *The AEI-John Thompson Nuclear Energy Co Ltd*

IN THE DESIGN of the British MkI* gas-cooled, graphite-moderated nuclear power stations there are a few major differences which strike the eye immediately. These points are summarized in the table. For pressure vessels there are sound arguments in favour of both the sphere and the cylinder.

Core geometry

To minimize neutron leakage and hence the amount of uranium in the core, the ratio of core surface area to contained volume should be as small as possible. The best geometrical shape is therefore a sphere, but in practice the uranium must frequently be inserted and withdrawn from the core, and coolant gas must be passed through the uranium-containing channels. The practical choice lies between the cube and the right square cylinder.

The need to reduce blower power having dictated that the coolant shall be pressurized the core shape must be compatible with a practical form of containing vessel. Here the choice is limited to two; sphere or cylinder. Although it might seem at first sight that the cylindrical core should be arranged with axis horizontal within either a spherical or cylindrical pressure vessel, in both cases support of the core in the pressure vessel and support of the pressure vessel itself offers problems which lead to a vertical axis cylinder being the preferred arrangement.

While a right square cylinder is an ideal shape to use for neutron economy reasons, it is possible to vary the height to diameter ratio on such a core quite significantly without greatly increasing uranium investment. The table shows that Berkeley, Bradwell and Hunterston all have similar net outputs and the uranium investment is approximately the same although the D/L ratio varies from 1·56 to 1·93.

*The authors regard Berkeley, Bradwell and Hunterston as Mk I stations, with Hinkley Point as perhaps intermediate between these and a fully-fledged Mk II station.

Advantages of high pressure

In a conventional coal-fired power station the flow of furnace gases is maintained by forced and induced draught fans. At most the combined power consumption of these fans is not more than 1 to 1½ pc of the total output of a modern station. In the gas-cooled nuclear reactor power station the corresponding auxiliaries are the blowers which circulate the CO_2 through the core and boilers. The exact proportion of blower power employed expressed as a percentage of station gross electrical output, is not disclosed by the designers of the various Mk I stations but may be assumed to fall within the range 10 to 15 pc. The heat removed from the reactor core for a given coolant temperature rise is proportional to mass flow. Circulator power is proportional to mass flow × head loss. There is therefore a considerable advantage to be gained in working at higher pressure.

SALIENT DIFFERENCES IN GENERAL DESIGN OF MARK I NUCLEAR STATIONS

	BERKELEY	BRADWELL	HUNTERSTON	HINKLEY POINT
press. vessel shape	*cylinder*	*sphere*	*sphere*	*sphere*
core dia/height ratio	*1·75*	*1·56*	*1·93*	*1·76*
uranium wt per reactor—tonnes	*252*	*240*	*251*	*370*
no of gas circuits	*8*	*6*	*8*	*6*
type of blower	*axial*	*axial*	*centrifugal*	*axial*
blower motors	*induction*	*induction*	*d.c. motors*	*induction*
blower speed control	*hydraulic couplings*	*variable frequency supply*	*mercury arc rectifiers with phase shifters*	*variable frequency supply*
source of blower supply	*main sets v. unit t'formers*	*aux. turboalternators*	*main sets*	*aux turboalternators*
no of main turboalternator sets	*4*	*6*	*6*	*6*
size of turboalternator	*85 MW*	*55 MW*	*60 MW*	*93·5 MW*

Sphere v. cylinder

The formulae for working pressure in spheres and cylinders of identical diameter, shell thickness and material show that a sphere can withstand an internal pressure twice that of a cylinder. It would therefore seem obvious that a sphere is the most attractive form. However as we have seen, the core is in the form of a vertical cylinder and fits into a cylinder only very slightly larger than itself whereas a sphere capable of taking the same cylindrical core with reasonable working clearances must necessarily be some 40 pc larger in diameter.

In addition unless the sphere and core are supported at the equator additional tensile stresses due to self weight are induced in the shell whereas with a cylinder such stresses may be eliminated almost entirely. A cylinder can therefore be worked at a higher hoop stress and in practice the increase in working gas pressure by using a practical form of sphere is only 10–20 pc higher than the equivalent cylinder required to contain the same core.

The combined cost of pressure vessel and biological shield for the spherical vessel as compared with the cylindrical form is greater. Also the greater span of the biological shield roof with its labyrinthine penetrations accommodating control and charge tubes increases some already notable engineering problems.

Reinforced cylinders

However, due to the higher pressure that can be obtained from spherical construction the overall economics of the sphere and equivalent cylinder are similar for the range of output associated with the Mk I reactor. At lower outputs the cylindrical vessel shows an advantage. At higher outputs the sphere is more advantageous. If however, the gas pressure in the cylinder can be increased by reinforce-

ment of the barrel this advantage is reversed.

Some designers prefer the cylindrical vessel for a number of practical reasons quite apart from economics. For example, the head room over the core is independent of diameter and therefore for the same gas pressure as much space as is required can be made available above the core for the accommodation of charge tubes and fuelling devices.

Number of circuits

Gas circuits comprise boilers, ducting and blowers, together with appropriate expansion joints and valves. For a given type of heat transfer surface the total cost of boilers varies fairly closely with total heat output, being largely independent of number employed. The main saving by using a reduced number of boilers occurs in the foundation civil works required to support them, but the number of boilers is more likely to be influenced by the construction method adopted. The principal limiting feature in deciding the number of gas circuits is the design of duct work and its flexibility. Blowers can be built to individual sizes which impose no limitation on the number of gas circuits employed.

Three out of the four British commercial stations employ the single-stage axial type of blower on the grounds of small physical size, efficiency and cheapness, a horizontal shaft arrangement being adopted in each case. Hunterston however employs a vertical spindle centrifugal blower built into the bottom of the boilers.

Blower systems

Three out of the four stations favour squirrel-cage induction motors for blower drive on the grounds of simplicity, reliability and cost. Hunterston utilizes d.c. commutator motors, the advantage being, of course, direct control of speed. With regard to control of blower speed, one station uses hydraulic couplings, two use variable-frequency auxiliary supply from separate turboalternators and Hunterston uses mercury-arc rectifiers with phase shifters to supply its d.c. motors. Hydraulic couplings have the advantage of eliminating special electrical supply arrangements but tend to be inefficient at low speeds. However, as these stations are to be operated on base load this is not a very important weakness. The use of variable-frequency auxiliary turboalternators has the merit of flexibility but the disadvantage of additional capital cost and space requirements. The use of mercury-arc rectifiers and phase shifters displays advantages and disadvantages probably mid-way between the other two systems. The relative merits of driving large auxiliaries such as the blowers from the main turboalternator sets via unit or station transformers or from separate auxiliary turboalternator sets, have been the subject of controversy in conventional power stations for many years. In Britain conventional practice favours the use of main sets feeding through unit and/or station transformers.

World Power Conference, Montreal 1958. Paper 88 B3/6.

NUCLEAR TECHNOLOGY | materials

Mechanical properties of uranium-molybdenum alloys

by M. B. WALDRON, R. G. BURNETT and S. F. PUGH *AERE, Harwell*

ALLOYS of the uranium-molybdenum system were selected for a preliminary determination of the mechanical properties at temperatures up to 800°C. At the start, very pure uranium was not available in sufficient quantities for an extensive programme, but it was considered that useful conclusions could be drawn from the properties of alloys made from less pure material.

Fabrication of alloys

a. *Casting.* A series of alloys containing from 0·85 to 13·5 pc molybdenum in uranium were melted in graphite crucibles in a vacuum high frequency furnace and cast in graphite moulds. High purity molybdenum chippings were placed underneath a uranium billet in the crucible. On heating, the uranium melted and flowed around the chippings, alloying with the molybdenum. The temperature of the melt was then increased to 1500°C and held for 30 minutes to completely dissolve the molybdenum. The alloy was cast into 2½ in. dia. × 18 in. long graphite moulds and check analysis of the bars were taken.

b. *Forging (0·85–7·8 pc molybdenum)* The 2½ in. dia. billets in this range of composition were forged at 850°C in air between flats to roughly 1¼ in. dia., finishing between hemicylindrical dies to ⅞ in. dia. The 0·85–2·2 pc molybdenum alloys were too soft to handle at 850°C after the section had been reduced, and for these, the temperature was dropped for the final stages to 750°C, the lowest at which they could be conveniently kept in the γ range. The alloys containing 10–13·5 pc molybdenum did not deform under the hammer even at 950°C, but tended rather to crack. In the α range (about 640°C) all the compositions yielded bars too hard for forging.

c. *Rolling (0·85–7·8 pc molybdenum)* The temperatures that had been used for forging were adopted for rolling the ⅞ in. dia. forged bars to ⅝ in. dia. in 3 equal passes. Rolling of all bars in the range 0·85–7·8 molybdenum was possible, but as with forging it was not possible to roll the 10–13·5 pc compositions even at 950°C. Cracking on cooling was evident after rolling the 1·5 molybdenum alloy. The finished bars ⅝ in. dia. × 3 ft long were cut into 18 in. lengths for heat treatment to produce the structures required.

d. *Extrusion* A separate batch of uranium containing 10·9 pc molybdenum was extruded in a zircaloy sheath with a reduction area of 16:1 at 850–880°C using a low ram speed of ½–1 in./second. If extrusion at normal speeds was attempted transverse cracking occurred.

Testing equipment and methods

A vacuum hot hardness tester was built capable of reaching 900°C and of being maintained at a vacuum of 10^{-5} mm/Hg. A diamond indentor of standard 136° pyramidical angle was directly loaded through a Wilson seal onto the specimen which rested on a platform surrounded by a nichrome wound heater.

The tensile test pieces were machined after heat treatment to 0·338 in. diameter along a parallel portion in the centre of the test piece with ½ in. BSF threaded ends. All hot tensile testing was carried out in a gas box containing purified argon.

The kinetics of the decomposition of quenched α uranium was investigated by measuring the changes of hardness with time of alloys containing 6·6 pc molybdenum at tempera-

tures of 300°, 400°, 450°, 500° and 580°C. Aging tests were also carried out at 400°C on all compositions from 0·85 to 13·5 pc molybdenum.

The uranium-molybdenum alloys are susceptible to a wide variety of heat treatments and develop interesting properties over certain composition ranges which may be of technical advantage. Three groups of alloys can be distinguished in which hardening is due respectively: to solid solution of molybdenum in α uranium, to formation of $\alpha + \gamma$ dispersions and to solid solution of molybdenum in γ uranium. Solid solution hardening of α uranium will be of value where neutron economy is of the greatest importance. The disadvantages of the non-isotropic behaviour of the α structure will of course remain although they may be modified by the greatly increased tensile strength and hardness relative to the unalloyed uranium. Alloys in the second group over the range 6–10 pc molybdenum depend for their properties on specific heat treatments; they can be homogenized to obtain high ductility which favours working operations with the possibility of a precipitation treatment which develops a greater tensile strength accompanied by low elongation. The range above 8 pc molybdenum in which the hardened γ solid solution can be retained down to room temperature on cooling is probably the only one in which the alloys have useful properties at temperatures above 600°C.

Effects of irradiation

It would be expected that irradiation would substantially reduce the properties of alloys in the first two ranges by reducing the stability of the two-phase dispersions. There is some evidence that alloys in the third range retain useful mechanical properties at elevated temperatures to a high burnup.

Alloys in this composition range have been irradiated up to 0·5 pc burnup of all atoms at temperatures of 500 and 700°C. These tests have shown that fission product gas swelling is reduced as the molybdenum content is increased. This is primarily attributed to strengthening of the α-uranium matrix.

The ductility of the alloys in the present investigation was probably affected by the non-metallic inclusions. The extruded alloys were more ductile than cast alloys, but soaking an extruded 10·9 pc molybdenum alloy at 450–550°C resulted in embrittlement.

UKAEA report AERE M/R 2554. HMSO 1958: 7s.

Machining irradiated uranium

by D. SHAW and W. G. HUFTON *UKAEA Industrial Group*

THE LACK of information on the tensile properties of irradiated uranium is due principally to the experimental difficulties involved. Results so far published are from the United States and cover only a limited range of irradiation doses and temperature. It was therefore decided to investigate at Windscale the effects of irradiation on the tensile properties of uranium.

At the outset it was clear that the problem could be approached in one of two ways. Test pieces could be either machined from unirradiated metal and subsequently irradiated, or they could be turned from irradiated bars. The former method would avoid the difficult machining problem, but would introduce substantial delays and difficulties in preparing and irradiating the test pieces. For this reason, the second approach was preferred.

Making tensile specimens

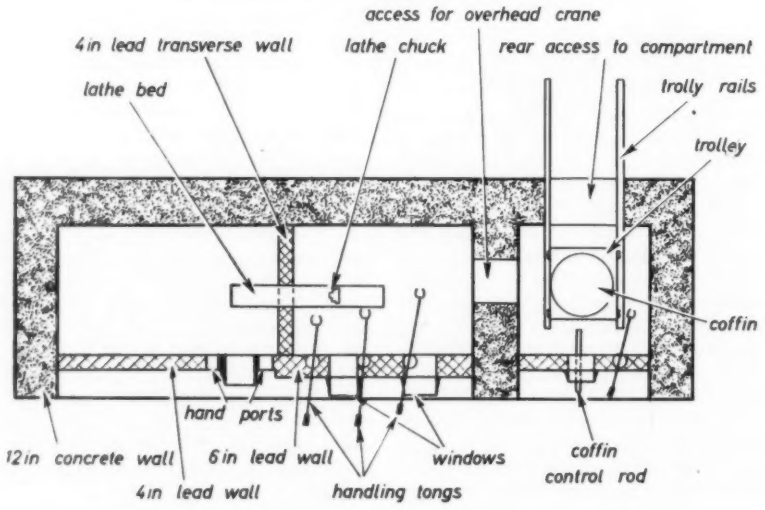
The lathe was housed in a standard Windscale shielded fumehood, 9½ ft long, 3 ft wide and 3 ft high, with the base 3½ ft above floor level (fig. 1). The base, back walls and sides were made of 12 in. thick concrete lined with lead sheet ⅛ in. thick. To the right of the cell a shielded compartment, 3 ft wide, was available for loading and unloading operations.

It was decided to prepare the standard No 14 Hounsfield tensile test piece for which a piece of uranium bar about 2¼ in. long is required. It is planned to allow sufficient cooling time for the activity to reach 80 curie-MeV before machining. Thus the main part of the front wall of the cell could be built in 6 in. thick lead, and other parts of the wall not directly in front of the lathe in 4 in. thick lead.

A Myford, model ML7, 3½ in. centre lathe was used, bolted in an inverted position to a heavy channel section frame. Thus swarf was prevented from falling into the lathe bed casting and other crevices.

In normal workshop practice, approximately four tools would be used in turning the test piece. In the present operation it was important to keep the number of tool changes to a minimum. Trials on unirradiated material showed that two tools were sufficient. These comprised a 'roughing' tool and a 'profiling, parting-off' tool. The latter was ground on each edge to the profile radius and was made fairly small in width for parting-off. The trials also showed that carbide-tipped tools were satisfactory, but that high-speed tools quickly deteriorated. As regrinding of the tools was not possible, it was found economical

Access to the lathe is by 3-ft long tongs (Fig 1)



to use replaceable carbide tips. A standard 'Wimit Econotip' was used for roughing, but a sepcial tip had to be made for the profiling and parting-off operations.

Swarf disposal

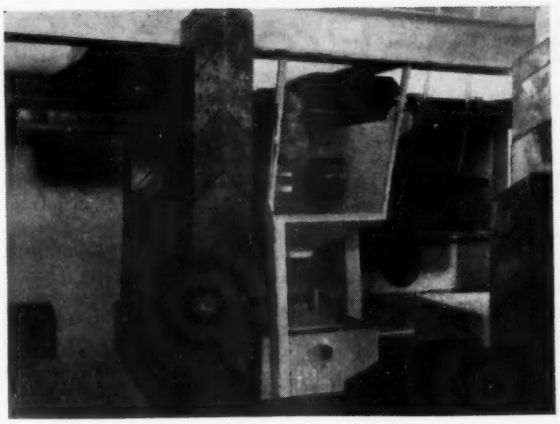
The lathe chuck was enclosed on three sides by a funnel, the front face of which was in perspex. The swarf drops into a mesh-bottomed container, underneath the funnel. When full, the container is placed in a larger can and a fluid mixture of builders plaster and water poured into it. After approximately one hour, the plaster is set hard. In this way potential hazards such as spread of contamination and combustion of the swarf were avoided.

It was found that the depth of cut that could be applied to the irradiated bar was smaller than that for unirradiated uranium. During the 'roughing' operation, the maximum cuts were 0·040 in. and 0·060 in. for the irradiated and unirradiated material respectively. On the whole cuttings from the irradiated bar were smaller than those from the unirradiated bar, and there was no tendency for long-curled turnings to be formed; otherwise there was little difference in machinability. Although a few of the turnings ignited during turning, they were rapidly extinguished and there was no air contamination.

With the equipment described, single-shoulder tensile test pieces, not more than two inches in length, can now be turned from irradiated uranium bars to tolerances of ± 0·001 in. in diameter and ± 0·010 in. in length.

Tensile testing was carried out on a Hounsfield Tensometer modified to permit remote handling of the specimen behind a lead enclosure.

To commission the apparatus and to prove its performance, a test piece was machined from a piece of 'as cast' irradiated uranium of indeterminate history. The results from the tensile test on this, and on a piece of similar unirradiated uranium, are quoted below.



The lathe is inverted so that swarf falls straight into the collection chute. The tail-stock is not used so that the maximum length of workpiece is only about 2 in. The tool-post is moved by a handwheel drive through bevel gears so that the operator's hand is not in the line of direct radiation from the workpiece (Fig 2)

CONDITION	0·2 PC PROOF STRESS (t.s.i.)	U.T.S. (t.s.i.)	ESTIMATED PC ELONGATION
as cast, unirradiated	25·0	32·0	3·8
as cast, irradiated	34·2	35·0	0·35

Other than noting that the proof stress of the irradiated material is appreciably higher, and the elongation substantially lower, than the corresponding values for the unirradiated material, it is not proposed to comment further on these differences.

UKAEA report IGR TN/W 905. HMSO 1958: 3s.

NUCLEAR TECHNOLOGY | irradiation

The Mk II isotope handling calculator

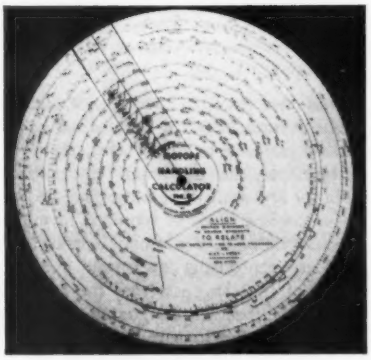
by R. WEST *Isotope Division, AERE, Harwell*

THE WIDE and increasing use of gamma sources, particularly in less familiar hands in industry, demands a ready method of calculating the hazard. At a single setting this calculator interrelates source strength, lead screening thickness, distance from source, and gamma doserate (and maximum safe handling time per day). To keep the instrument self-contained and simple, its scope is restricted to the seven most widely used gamma-emitting isotopes: Na-24, Co-60, Ra or Rn, Ta-182, Ir-192, Au-198 and I-131.

This model is actually Mark II but it differs from the Mark I only in the revised calibration for Ir-192 and revised doserates recommended by the ICRP. Made in white plastic with a transparent cursor, the instrument comprises two concentric discs of 22 and 17 cm diameter marked with the following scales:

1. Outer scale of large disk—gamma doserate in roentgens per hour (*D*) and maximum safe handling time per 8-hour day
2. Inner scale of large disk—distance from source in cm and in. (*d*)
3. Outer scale of small disk—source strength in curies (*C*)

The new calculator is about 9 in. dia. It uses the new ICRP doserates



4. Seven inner scales of small disk—lead thickness, scale for each isotope.

The calculator is used either by aligning scales 2 and 3 to relate 1 and 4, or vice versa.

In the simplest terms, handling and shielding factors are related by

$$D = \frac{CRK}{d^2}$$

where K is the fractional transmission through an absorber and R is the doserate given by the unshielded isotope (R/h/curie at distance d).

The various values of R for each isotope are incorporated by scale relationships. Values taken of K for each isotope are the results of attenuation measurements and are expressed in terms of lead thickness in inches on the seven innermost scales.

Calculators are available from the Isotope Information Office, Harwell.

UKAEA report AERE I/R 1063 (revised). HMSO 1958: 1s 9d.

New Product Survey

PLANT · EQUIPMENT · INSTRUMENTS · MATERIALS

REACTOR PROBE

flux and fuel distribution

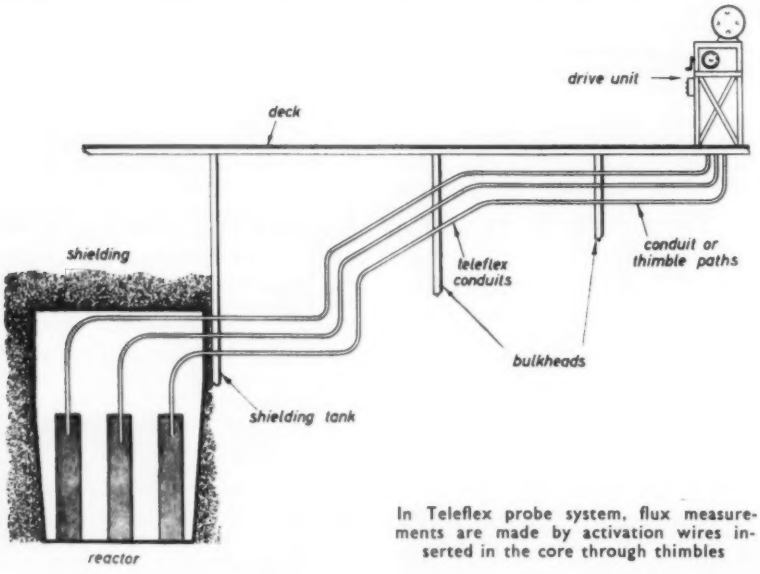
A reactor probe system developed by their US associates, Teleflex Inc, has been announced by Teleflex Products Ltd in the UK. Based on the use of activation wires and neutron sensitive thermopiles, the system is adaptable to: power distribution, time and space variations of burnup, neutron spectra and flux measurements.

Flux distributions are measured by activation wires contained in hollow titanium cable, inserted into vertical 304 stainless steel instrument thimbles strategically located within the core. The activation wires are individually or simultaneously conveyed into the core on the end of Teleflex carbon steel drive cables by a remote positioning mechanism and exposed to the neutron flux for a specified period. A detecting nuclide, uniformly distributed throughout each activation wire, becomes activated by neutron absorption during this time interval. The wires are now withdrawn from the instrument thimbles and the specific beta-activity emanating from the detecting nuclide measured along the wire by an automatic scanning system. The distribution of activity along the length of the wire is proportional to the thermal flux distribution.

In the measurement of fuel distribution, small diameter wires doped with reactor fuel are inserted into selected thimbles. These wires remain within the reactor at all times, except for short intervals when they are removed for a fuel distribution or flux distribution measurement. Thus, the uranium isotope burnup percentages at a given point in a fuel-doped wire should be identical to those that would be found in a fuel element at the same location, with a correction for differences in self-shielding. The ratios of the isotope burnup percentages or of remaining isotope concentration can be directly related to the remaining total fuel concentration at a given point.

Neutron-sensitive thermopiles are used for instantaneous point measurements. They are attached to titanium thermoelectric cable which conveys the output signal to a fast-response recorder located in the read-out room.

The construction of the Teleflex instrument thimbles, and their penetration into the reactor pressure vessel is such as not to impair or limit the integrity or life of the reactor. Since the detecting elements and adjacent lengths of cable will be exposed to high fluxes, they are designed to the maximum extent possible for low activation and/or fast radioactive cooling. This is required to minimize shielding and personnel protection requirements during operation and removal of the elements from the reactor. Decay positions are designated and used during operation to permit radioactivity.



In Teleflex probe system, flux measurements are made by activation wires inserted in the core through thimbles

The Teleflex position mechanism provides a means for inserting, positioning and removing the detecting elements from the instrument thimbles. Coincidental insertion and removal of the detecting elements permits simultaneous and equal activation times for all wires in a given measurement. The drive mechanism drives, controls, and stores the various drive cables and detecting elements.

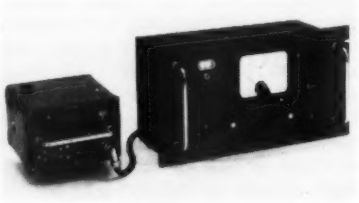
Tick **No 201** on reply card

GAMMA RAY ELECTROMETER

for U slurry concentration

A gamma ray electrometer has been developed by Electronic Instruments in conjunction with the UK Atomic Energy Authority, to meet a special requirement for measuring the concentration of uranium ore in a slurry.

The measurement has to be made whilst the slurry flows through a steel pipe in an ore treatment plant. The absorption of the gamma rays in the pipe varies with the density of the slurry. This change in absorption, however, is small compared with the total gamma flux incident on the ionization chamber. Therefore, an instrument is required which will measure a small change in the presence of a large signal.



Measuring gamma-ray absorption in a slurry, EIL electrometers are in use at AEA uranium processing plants

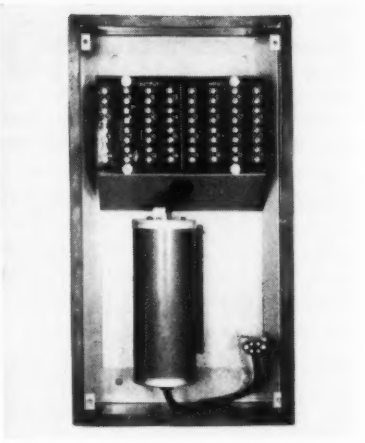
The Electrometer is designed around the E.I.L. *Vibron* unit, an electro-mechanical device which replaces the electrometer valve and provides a far higher degree of sensitivity and stability than can be attained by conventional valve circuits.

Tick **No 202** on reply card

COLD JUNCTION BOX

for remote thermocouples

A cold junction box, for use when a large number of thermocouples are sited an appreciable distance from their indicating or measuring points, has been introduced by Sunvic Controls. The unit can be installed on the plant and thermocouple leads gathered to it for automatic compensation. The distance from cold junction box to indicating/measuring point can then be covered by ordin-



Sixteen pairs of copper-constantan leads are contained in Sunvic's cold junction box

ary copper cable with a consequent considerable saving in cost.

In addition the cold junction box gives greater accuracy than normal methods of compensation and is usually set to maintain a temperature of 60°C ± 0·1 pc. This accuracy is essential for most forms of data handling.

The unit accommodates sixteen pairs of copper constantan leads, the sixteen compensating cables and a cold junction thermostat. A test thermometer can be inserted to check the performance of the latter.

Tick **No 203** on reply card

ELECTRODE FOR MILD STEEL

fast and easy flowing

A new electrode, designed for fast and economic welding of mild steel, is now being manufactured by Quasi-Arc Limited. Known as the *Mirrospeed*, it is said to be easy to use and a 'touch' technique is preferred so that even a moderately skilled welder can achieve sound results. The electrodes are suitable for production work where high output and good weld profile are of major importance since the characteristics include smooth running, quiet arc and fluid, yet easily-controlled, slag. Easy slag detachability enables de-slagging to be kept to a minimum.

The electrodes are satisfactory for welding in all positions and are particularly suitable for flat and horizontal-vertical fillet welding and flat butt welding. In fillet welding the electrode can be 'drawn out' to give very long run lengths. In addition, it is usual to use one size larger gauge than normal, so that even longer runs can be made at high speeds, and less time is lost in changing electrodes.

Mirrospeeds are manufactured in sizes ranging from 12 swg to 4 swg inclusive. They are fully extruded and coded under B.S.1719:1951 classification as E.217, corresponding to the AWS/ASTM classification E.6012. They can be used on a.c. or d.c.; in the case of d.c. the electrode can be connected to either pole. The electrodes conform to B.S.639:1952, and are approved by Lloyds Register of Shipping and the Ministry of Transport and Civil Aviation for welding mild steel in all positions.

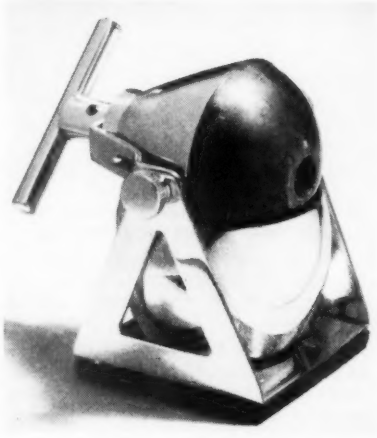
Tick **No 204** on reply card

NEW ISOTOPE CONTAINERS

lightweight for radiography

Main features of the new GammaX isotope containers for radiography are their low weight to protection ratio, simplicity of action and tolerance of bad weather conditions. Two sizes are available: one is for Ir-192 or Tm-170 giving a doserate of 7·5 mr/h at one metre when loaded with 3 curies of Ir-192. Weighing only 7½ lb it is particularly suitable for site work; a lead-lined box is provided for protection during transport. The second container, recommended for factory use, has a minimum protection of 1¼ in. of lead and weighs under 20 lb. This will shield 35 curies of Ir-192 or 4 curies of Cs-137 to 7·5 mr/h at one metre.

Made throughout from non-rusting materials, they have no cast parts except for the protective thickness. Other features are complete protection of the source from corrosion or damage both



GammaX isotope holder gives all-round protection for radiography

in the container and handling rod. When using double-wall techniques the source can be placed about ⅛ in. from the specimen without removal from the container.

Tick **No 205** on reply card

SUPERFINE MoS_2 POWDER

particles down to ¼ micron

The emergence of molybdenum disulphide as a solid lubricant capable of withstanding pressures of ½ million psi and over, and of operating in high temperatures, has been an outstanding development during the past few years. However, the particle size reduction of MoS_2 has always been a difficult undertaking. Ordinary milling and similar processes are ruled out as they cause oxidation of the material leading to the formation of molybdenum trioxide which has no lubrication characteristics.

The finest powders generally obtainable have average particle sizes of ¼ micron to 3 micron. It is possible to reduce MoS_2 particles in liquids, in ball or roller mills. But it is often found that such quasi-colloidal dispersions are not as effective as the flake materials. There appears to be a loss of some of the ad-

In molybdenum disulphide by Moly-Paul, flake-like structure has been retained; no change in pH was detectable

vantageous properties of MoS_2 possibly also due to oxidation.

Moly-Paul now inform us that, by means of a quasi air flotation method they have produced, on a commercial basis, a molybdenum disulphide powder of average particle size of ¼ micron to ½ micron. Trial production batches have shown considerable consistency of results. The particle size distribution of this new Moly-Paul Superfine Powder shows a distribution of over 65 pc under ½ micron particle size. The advent of Moly-Paul superfine powder is likely to lead to great advances being made in the field of liquid dispersions of molybdenum disulphide.

Until full production commences, experimental samples only will be available to interested parties.

Tick **No 206** on reply card

SPECIAL VOLTMETER

measures low frequency r.m.s.

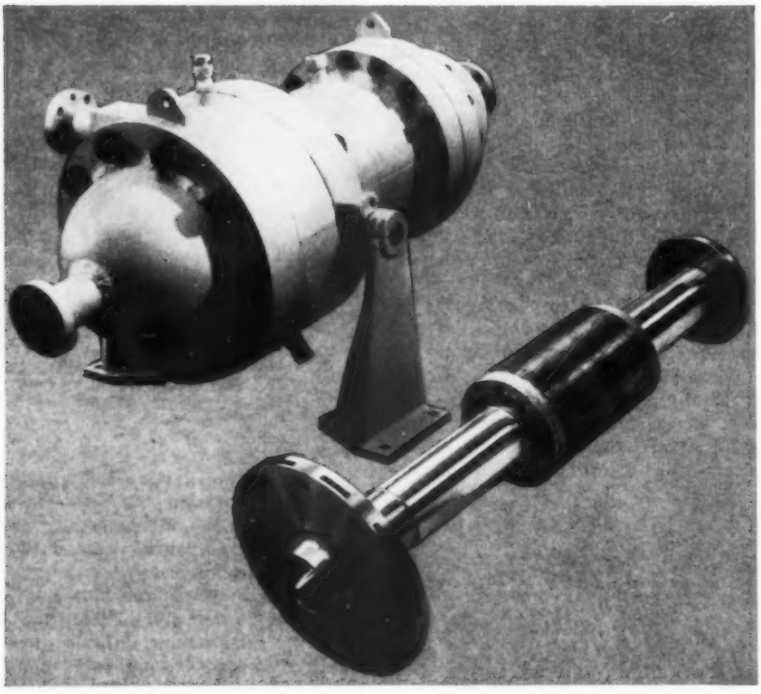
Just developed, and now available from Crompton Parkinson, is a special type of voltmeter which will be of particular interest to engineers who are faced with the problem of reading steady r.m.s. voltage values on very low frequency, 3-phase a.c. supplies. Such a problem arises, for example when, for the operation of nuclear reactor control rods, use

is made of very low-speed motors on a 3-phase a.c. supply, the frequency of which varies from zero to 2 c/s. When taking voltage measurements at these low frequencies, the instantaneous value of voltage varies so slowly that the pointer of an ordinary instrument has time to follow it, instead of indicating a steady r.m.s. value.

The new instrument is basically a d.c. moving-coil voltmeter operated from a phase-splitting network with full-wave rectification. This network produces twelve impulses per cycle across the instrument movement, thus reducing the magnitude of the applied ripple voltage and simultaneously increasing its frequency. As a result, the instrument may be used to indicate the r.m.s value of an applied 3-phase voltage at any frequency from 0 to 2500 c/s.

Tests have shown that the pointer deviation either side of the mean indication amounts to no more than 0·3 pc at 2 c/s, 0·7 pc at 1 c/s and 5 pc at 0·04 c/s. Both switchboard and portable forms of the instrument are available.

Tick **No 207** on reply card



Ruston's nuclear division, working on 5–25 MW power stations, developed this gas-bearing circulator. Overall length of circulator and rotating assembly is 4 ft 9 in.

GAS-BEARING CIRCULATOR

for auxiliary reactor circuits

Ruston & Hornsby recently announced the introduction of a gas-bearing circulator. This unit has been developed by the company's Nuclear Division and is intended for use where it is necessary to circulate gas at high temperature and pressure without leakage—this requirement is frequently encountered in the nuclear field. In order to eliminate the need for oil bearings, the rotating assembly of the circulator is carried on bearings which use the pumped gas—air, carbon dioxide or helium—as a bearing fluid. The production of these bearings calls for exceptionally high standards of machining, the shaft diameter being correct to within 50 micro inches over a 5½ in. length.

The capacity of the class NFB circulator was chosen after carrying out an investigation of the probable requirements of a number of potential users, both in the UK and abroad. As produced, the unit is capable of satisfying current demands for engineering laboratory experiments and for the auxiliary circuits of large gas-cooled reactors.

The gas-bearing circulator will be used in experiments within Ruston's own Research Centre to further the work on the design and development of nuclear power stations of 5–25 MW output. Design limits are 450 psia and 450°C. Speed range is 10:1 when driven by a variable frequency a.c. supply.

Tick **No 208** on reply card

IN BRIEF

Temperature probe Texas Instruments recently showed in the US a new *Sensistor* silicon crystal sensing device. They have a constant positive temperature coefficient and are made in very small sizes.

Tick **No 209** on reply card

Remanent relays Telephone Mfg Co announced that P.O. type 3000 and 600 relays are now available with remanent cores. They remain latched up on receipt of a signal until cancelled by another.

Tick **No 210** on reply card

Microsecond stopcock Venner Electronics have given advance details of new unit, type TSA 24. It is fully transistorized.

Tick **No 211** on reply card

Electric hoist New ½-ton Matterson model is available for max. lifts of 23 and 45 ft as a runway hoist or for fixed suspension. Control is by pendant push buttons.

Tick **No 212** on reply card

Coolant clarifier Available from stock from Philips Electrical is their new *Magna-Drum*. Made in a ceramic, it is magnetic all over its surface. Cutting oil flows of 300–5000 gph can be handled and all swarf removed.

Tick **No 213** on reply card

Instant Tin is the name of a new plating solution brought out by Desert Laboratory. Brief immersion at room temperature gives workable deposit—ideal for printed circuits, rivets, nails etc—and heavier coating can be obtained if required.

Tick **No 214** on reply card

Strain gauges Available either as expander or bender elements are two new types of vibration strain gauges, produced by Technical Ceramics Ltd. They are made in piezoelectric ceramic, have a wide temperature range and flat temperature coefficient.

Tick **No 215** on reply card

Graphite heat exchanger Further model with a heat exchange area of 300 sq ft has been added to Powell Duffryn Carbon Products range. There are now 30 standard models covering areas of from 4 to 300 sq ft.

Tick **No 216** on reply card

Germanium diode Dimensionally identical with VA 713 this diode (VA 719) has increased current rating of 20 amp at 35°C. Available as a single unit or in multiple units fitted with fins and assembled into stacks taking up to 130 amp and 223 V (d.c.).

Tick **No 217** on reply card

Cross Section by GRACCHUS

NEWS that Sir John Cockcroft has just been to Russia and is now in Japan leads me to the inescapable conclusion that someone is trying to retire him, using Parkinson's method (see *Parkinson's Law*, p 109 *et seq.*). Briefly, this involves an intensive sequence of high-level meetings and social functions liberally interspersed with long-distance air travel at frightfully inconvenient times. After a few months of this treatment, broken by odd days back in the office with a carefully-arranged mounting in-tray, most victims should be reaching the state where they feel they are too old for the game and retire, much to everyone's satisfaction. This year alone Sir John has been to Spain, Denmark, Switzerland (twice), Italy, Belgium, Irak and now Russia and Japan. In addition he has made innumerable trips up and down the UK making speeches and attending functions of all kinds. He is indeed Britain's atomic ambassador extraordinary and we should be grateful for the splendid work he is doing, but one begins to wonder how long he can keep it up at this rate.

Like the generals, Sir John must have a great fund of memories and I hope he is taking steps to ensure that the full story of the early days of atomic energy in this country is recorded for posterity.

CLIMBDOWNS are always difficult to manage without loss of dignity but a good example of this type of feat recently came to my notice from the British Standards Institution. Last year the Institution published its controversial British Standard 2929—*Safety colours for use in industry*—which, amongst other revolutionary proposals, recommended that since red was to be taken as a sign of danger a red cross on the first aid equipment was inappropriate. Green, being the colour for safety and security, BS 2929 said in effect 'out with red crosses, in with green.' This was certainly pretty strong meat and I must say I have yet to see it used. However the idea has now been killed off at a very early age because it seems that the green cross 'might possibly be considered as an infringement of certain registered trade marks.' What rows, what threats I wonder lies behind this graceful little statement? To get over this impasse the BSI now recommend the words FIRST AID in bold white letters on a green rectangular background. What nonsense! The international red cross has been universally understood and respected for 50 years or more and it was a mistake in the first place to try and put over this green business for crosses. Now it's failed, to attempt to preserve the sacred cow of a principle by this absurd green box just looks like obstinacy. I'm all for progress and hate to be thought a backwoodsman but even I recognize that there's some things you can't alter, however much it might be desirable purely on grounds of principle. Come along BSI, think again about this! You'll have plenty of time.

IT IS, I think, generally agreed that the UKAEA's press and public relations department do a very good job but I sometimes wish they could be a bit more informal in the way the Americans are. For example I recently saw two strangely contrasted press releases, one on the AGR from the AEA and the other on further contracts for EBR-II, put out by the Argonne National Laboratory. The British effort was very terse and factual but it was completely impersonal and left a lot unsaid. The Argonne release was much more relaxed and yet gave more information. While we just have cold facts thrown at us, in America the same sort of facts are always attributed to someone or other (. . . said Leonard J. Koch, deputy director, Reactor Engineering Division). It may be argued that this adds nothing, but I am old-fashioned enough to believe that people are interested in people and that the inclusion of names of men associated in an important new project like the AGR make a far more readable story—as well as giving credit to those concerned.

The AGR release, too, is awfully vague about the contractual arrangements made by the AEA. Were these jobs put out to tender? What is the value of the individual contracts? Argonne on this subject is quite explicit: not only does it give the value of the successful contract but also that of the eleven unsuccessful bids. I suppose it's just dear old commercial security at work again but it is extraordinary how little there is of this in the United States where competition for every atomic energy job is fierce and unrelenting. Isn't it about time we had a bit less of this in the AEA? After all they are spending taxpayers' money and the public have a right, where national security it not involved, to know whether or not the Authority is getting its work done at the best price. Well done, I say, to the firms who have got these AGR jobs but I would be happier if I knew just how they came by them.

ALTHOUGH the coroner's inquest returned an open verdict the case of Lieut. Franklin remains somewhat of a mystery. Franklin, it will be recalled attended the H-bomb tests at Christmas Island in 1957 as a radar officer in the aircraft carrier *Warrior* and later died of aplastic anaemia. At the inquest it was reported that a post-mortem did not reveal any abnormal amounts of strontium-90 in the bone and apparently no other cases of diseases of this kind have been reported among those assisting at the tests. Yet it is known that radiation can be a cause of aplastic anaemia and Lieut. Franklin had apparently a completely clean bill of health until his fatal illness. Thus an open verdict and a continuing mystery. In the words of Mr J. F. Glanville, for Mrs Franklin 'one of the most alarming aspects of radiation is our ignorance of it.'

WINDSCALE—a.d. 2008

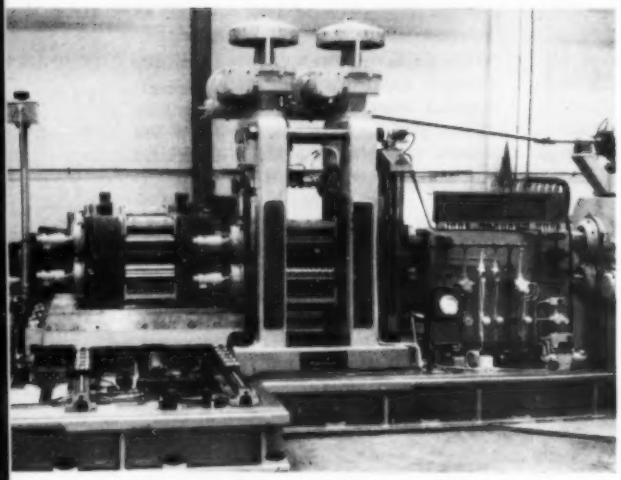
I met a traveller from an antique land
Who said: Two vast and trunkless legs of stone
Stand in the desert. Near them on the sand,
Dog-eared, a short White Paper lies, whose damn-

ing verdict and words of cold command (338)
Tell that its author well those clangers read
Which yet survive, stamp'd on these lifeless things,
The hands that dropped them—proper carve-ups made;

And on the pedestal these words appear
'My name is Alexander. Oh what sins!
Look on my works ye Ops staff and despair!'

Nothing beside remains. Round the decay
Of that colossal wreck, boundless and bare
The lone and level sands stretch far away.

with apologies to P. B. Shelley



PROGRESS IN INDUSTRY

British rolling mill for France

This Stanat/Mann 2-high/4-high combination mill is designed for argon glove-box operation. All operations, including roll-changing, are carried out by remote control. In this view, the hot section rolls are in place.

AN OUTSTANDING British export order has recently been completed by Albert Mann's Engineering Co Ltd. It consists of a Stanat/Mann rolling mill for the French Commissariat à l'Energie Atomique and the machine is shortly to be delivered to Saclay where it will be installed in a very large glove box and used for working plutonium and other radioactive and toxic materials. *Progress* was recently invited by Mann's to visit their Basildon, Essex factory where the mill had been fully assembled and we were able to see a demonstration of the completely automatic roll-changing which is a feature of the machine. The company have already supplied special small mills of this general type to the UKAEA for Aldermaston, Culcheth and Dounreay, to the French CEA and to the Belgian Centre d'Etudes. The latest mill however, with rolls 10 in. dia and 14 in. face-width, is considered a great advance since all operations are controlled from a small console outside the glove box.

Ward-Leonard control

The mill is a reversing combination machine with four sets of rolls, viz.: 2-high hot breakdown, 2-high cold intermediate, 4-high cold finishing and a hot rod section mill. Each set of rolls is self-contained in its own chocks and the sets not in use are held on a carriage which moves on rails alongside the frame. Individual roll units are slid across the carriage by a lead screw fitted with Pollard thrust bearings and driven through a pinion by a hydraulic motor. Power for the rolls is provided by a 100 h.p. Crompton Parkinson motor driving a pair of universal shafts through a double-helical reduction gearbox. This motor is supplied by a motor-generator set on a common bedplate working on the Ward-Leonard system.

Torque and pressure measured

The 2 h.p. infinitely-variable speed screwdown motor is mounted on top of the gearbox and drives the twin screw-down gears through a universal shaft. A Westool magnetic clutch enables individual adjustment of each side to be carried out. Armature current for the screwdown motor and field excitation for the Ward-Leonard set are supplied by a new system of pulse-controlled thyratrons developed by Mann's and is claimed to give very fine control of speed and torque. The rolling performance is as folows: max. rolling load 600,000 lb: rolling speed at constant torque, 5–80 fpm: rolling speed at constant power 80–160 fpm. Davy-united load cells are used to gauge the roll pressure and torque is measured by strain gauges cemented to both universal shafts, currents being taken out by means of slip rings. A 2-pen high-speed recorder is provided on the control desk for roll pressure and roll neck torque.

Electro-hydraulic system

Roll changing is done by a programmed sequence using an electro-hydraulic system. On selecting a given roll configuration on the console the following actions take place: the screwdown disconnects and rises to accept any roll configuration, the roll ends of the universal shafts are supported, the jibs retaining the chocks in the mill housing are withdrawn and the complete roll assembly withdrawn

Points of interest at rear of mill are as follows: 2 h.p. screwdown motor on top of main gearbox, twin universal drive shafts with raising gear on the mill frame, squared ends of roll units on traversing carriage

onto the carriage. The drive shafts are now adjusted in height to suit the new roll unit, the carriage is moved to offer it up and the unit is then driven into the frame where the squared ends of the drive shafts are waiting to enter the rolls. The jibs now lock the assembly and after the screwdown has been connected, the mill is ready for operation. To ensure perfect engagement of the drive spindles the sequence is locked by a photoelectric device so that it can operate only when the squared driving ends on the universal shafts are aligned with the female drive sockets on the rolls. Inching control is provided to bring the shafts to the correct position.

Components for the hydraulic system and the pump were supplied by Keelavite Hydraulics. The sequence control is carried out by solenoid-operated valves operated by relays which are energized by signals from Square D limit switches on each operation.

When installed, the entire mill will be in the glove box enclosure. For operation in argon atmospheres d.c. motors are undesirable as the gas is easily ionized, which causes electric breakdown. Thus the gearbox and motor are kept outside of the box, the fixed ends of the universal shafts entering through seals.

Also seen at Mann's on this occasion was a 5 in. dia by 5 in. face-width 2-high/4-high combination mill with three sets of rolls installed in a stainless steel glove box. This is shortly going to Dounreay to form part of a fuel element assembly line. Unlike the larger French mill, it is not however remotely controlled, roll-changing being done manually in gloves.

Bellows expansion joints for gas ducting

Prototypes for British power stations pass severe tests

ALL THE BRITISH nuclear power stations now building use several independent gas-cooling circuits for each reactor. To cope with thermal expansion the ductwork in each case incorporates a number of bellows joints which permit angular deflexions. In each design the ductwork geometry is arranged so that it lies entirely in one vertical plane: thus one degree of angular freedom is all that is needed at the joints. Across each joint the ducts are connected by external trunnions and pins lying normally to the plane of flexure: these ensure that there is no axial load on the bellows. Inside the bellows a short length of internal duct welded to one pipe projects with an adequate radial clearance into the other pipe. This smooths the flow through the bellows and protects the convolutions from possible erosion effects.

Substantial order

Bellows for Berkeley, Hunterston and Hinkley Point stations are being supplied by the German company, Industrie-Werke Karlsruhe through Engineering Appliances Ltd and Mr V. Westerman a director of the British firm, recently supplied us with some interesting details of these contracts. The bellows for Berkeley and Hunterston are of 5 ft dia and about 250 are required. Those for Hinkley Point, to the order of Babcock & Wilcox, are of 5 ft 6 in. dia. The units for Hunterston (GEC) are being supplied as complete units with restraints: the orders for Berkeley (AEI-JT) and Hinkley Point are for bellows only.

IWK have specialized in the convoluted and corrugated metal field for over 60 years and for these joints use a hot-forming process which results in a bellows thick enough to withstand very high pressures, yet thin enough to give adequate flexibility. The bellows are formed from steel sheet rolled into a tube and longitudinally welded by argon-arc. Using a special IWK machine, local heating is applied to the plain tube and the convolutions are rolled one at a time. During forming, an axial load is applied which slightly closes up the convolutions.

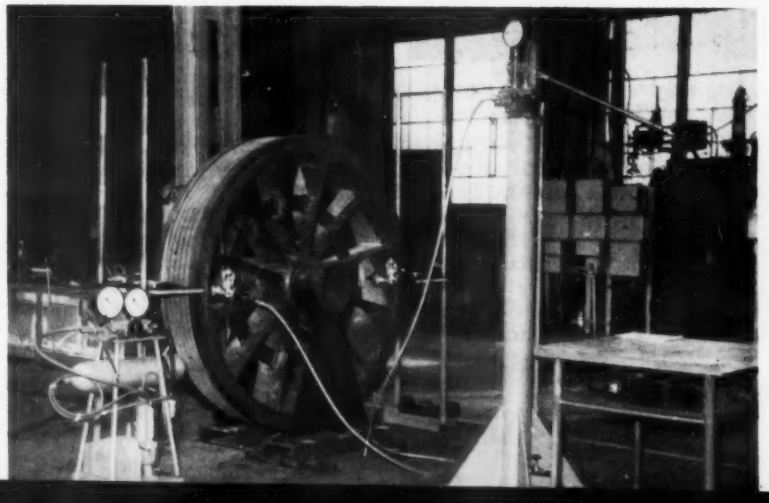
Test conditions

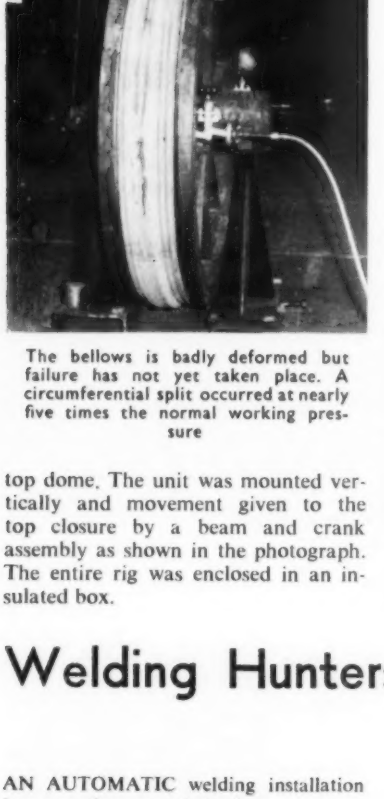
Following successful prototype tests on the 5 ft dia. bellows, designed for operation at 165 psi, 750°F, tests on the 5 ft 6 in. Hinkley Point bellows have recently been concluded in Karlsruhe. These included a life test at 230 psi, 770°F, and a bursting test—both to destruction. The bellows tested was $\frac{1}{8}$ in. thick of 1 pc Cr, 0·5 pc Mo steel, heat-treated after forming. Convolutions were of about $1\frac{1}{2}$ in. pitch with a height of $2\frac{1}{2}$ in. Eight convolutions were used for the life test and 5 for the bursting tests.

For the life tests on the Hinkley bellows the unit was mounted vertically in this insulated enclosure. Angular movement is given by the cross beam and crank mechanism

The test bellows complete with flanges and axial restraints was fitted top and bottom with flanged dished ends and filled with CO_2. Heat was supplied by a number of resistance heaters in thimble tubes entering the

Ultimate bursting pressure was determined by mounting a section of convolutions on the flat rim of a wheel-type assembly. The space between the bellows and rim was filled with water which was then pressurized until failure occurred





The bellows is badly deformed but failure has not yet taken place. A circumferential split occurred at nearly five times the normal working pressure

top dome. The unit was mounted vertically and movement given to the top closure by a beam and crank assembly as shown in the photograph. The entire rig was enclosed in an insulated box.

To start with, the assembly was given 1250 complete cycles through 3 deg. under hydraulic pressure. It was then given 1250 cycles with gas at 230 psi, 770°F and from this point to a total of 12,000 cycles the pressure and temperature were dropped to ambient every 500 to simulate working conditions. During this test a proof pressure of 460 psi was applied. After 12,000 cycles there was still no sign of failure so the angle was increased to a total of 5 degrees and at 14,520 cycles the bellows failed non-catastrophically, by a gradual circumferential crack.

Bursting test

The total load on the two restraint pins was over 716 tons and at the end of the test they were found to be in reasonable condition. During the proof test to 460 psi, strain gauging showed very small distortions and no permanent set.

To determine the absolute bursting pressure a bellows was mounted on the flat rim of a wheel-type assembly in such a way as to simulate the deflected condition. In other words, on one side the convolutions were compressed while on the other they were extended. The space between the bellows and the rim of the wheel was evacuated and filled with water. Ultimate failure at 1100 psi (5 times w.p.) took place circumferentially after a section of the convolutions had opened out. The tests were witnessed by Babcock & Wilcox Ltd and Lloyd's Register of Shipping (Land Division).

These tests with standard design and materials were considered very satisfactory but further tests are to be carried out with even higher grade material.

Welding Hunterston boilers

Quasi- Arc make special booms

AN AUTOMATIC welding installation incorporating one of the largest traversing and swivelling booms in the world is now in operation at Hunterston for fabricating the 73½ ft × 19½ ft dia boiler shells. Each vessel is built up from six strakes, consisting of three shaped plates, plus a top and bottom head and a supporting skirt, and all the fabricating is being done on site by the Motherwell Bridge and Engineering Co Ltd in a large

The big boom undergoes tests at Quasi-Arc's factory

welding shop. Basically the working area is divided into two bays: in the first the strakes and ends are assembled and tack welded, in the second the shells are completed by two specially built Quasi-Arc traversing booms. The longitudinal seams are welded first by the big boom, each strake being supported on one of the 40-ton roller-beds, and the strake is then passed via turntables to a parallel set of rails for circumferential welding by a smaller boom. Running on a separate track alongside the roller bed track, this normally operates at right angles to the axis of the section welded. At the same time the larger boom can be turned through 90 degrees and also brought into action over the second set of rails. It runs on the same rails as the roller beds and is constructed to swivel right through 360 degrees if necessary.

Speeds can reach 60 in./min

All welding is carried out by the *Unionmelt* process, each boom being fitted with two multi-power welding heads. In this method of welding two wires are used, each operating independently with its own power source, feed motor, voltage control and nozzle assembly, and both are fed into a common weld pool. Maximum current is 2000 amps, and this and the arc voltage can be controlled separately for each wire to give flexibility in adjusting weld shape and penetration. This helps to get the best results at maximum welding speeds, which are very high in this process—the welding speed traverse is controllable up to 60 inches a minute.

Both booms can carry out external work on vessels something over 20 ft in dia and the larger can cope with an internal weld 22 ft long. The operator either lies or sits at the welding head and from here he can control all functions of both the boom and the traversing roller beds supporting the workpiece.

The ten roller beds are arranged with welding speed traverse facilities so that welding can go on if it should be necessary to keep the boom stationary. Each roller bed can be operated as a separate unit, or any number can be ganged together. Power supply for rotation and traverse of the roller beds is variable d.c. supply obtained from a.c. via a grid-controlled thyratron circuit. This arrangement facilitates ganging, which can be carried out simply by connecting a plug on one bed to a socket on the next.

Another unusual feature of this shop is the transportation bogies which are used to move the shells around for stress relieving, pressure testing, etc. The weight of a vessel when filled with water is about 1,200 tons, and under this load the weight is not supported on the wheels of the bogie, but on special supporting pads, while a rubber mounting between the support cradle and the track wheel frame equalizes the load distribution.

Work on the first few shells is now well under way. Sixteen in all will be needed, and the 300 MWe station is due operational in June 1962.

Lying at the welding head the operator can control both the boom and the 40-ton roller bed carrying the strake

INDUSTRIAL NEWSDESK

AEA gets new data system

Panellit Ltd, a member of the Elliott-Automation Group, have built a new design of data processing and information system to the instructions of the AEA for application to one of their reactors. Similar in conception to the Panellit 609 set-up it uses an Elliott 802 computer and scans 600 points measured by thermocouples to detect variation in temperature level and rates of change of temperature. The installation has been designed to give a complete record of the 600 points scanned in two minutes for both level and rate of change and the facilities include a history of the last five scanning operations. The only moving parts in the entire system (excluding the output printer) are the input relays which connect the selected thermocouples, and Clare mercury-wetted types are employed; these relays have been tested to 3×10^9 operation without failure, and have a minimum of noise. Input signals for the thermocouples are fed to a high stability Offner differentially connected amplifier and from this point to an electronic analogue to digital converter before being passed into the computer. For reactor application some facilities have been duplicated in the interest of operational availability and a comprehensive self-checking system at the end of each scan automatically changes over to the alternative duplicate section to ensure continuous operation; at the same time a warning is given that part of the machine has not satisfied the built-in checking system. It is reported that the apparatus was originally ordered for Windscale. It will now go either to Calder Hall or Chapelcross.

US Babcock's latest research tool

The new pool reactor at Babcock & Wilcox's Lynchburg, Virginia, plant was officially dedicated recently and the occasion was taken to give visitors a tour of the nuclear laboratories. The reactor is in an open concrete pool and using 30-pc-enriched crimped plate-type elements it is designed for operation at 10-200 kW. The most interesting test facility on the reactor is the 'hot exponential loop.' This consists of a 3 ft dia. 9 ft long pressure vessel mounted into the pool wall very near the core. A sub-critical fuel assembly can be arranged inside the vessel which is then filled with hot pressurized water (up to 720 psi, 500°F). In this way closely simulated reactor conditions can be achieved and measurements made of flux distribution, neutron age, absorption, water-gap peaking and temperature coefficient. Flux scanning is done using the Teleflex wire activation system, based on a design by Knolls Atomic Power Laboratory. The activation wires are dysprosium-aluminium encased in hollow titanium flexible cables. After activation, the wires are scanned by a scintillation counter and the counts handled by an IBM data processer.

Kintel range to be made here

The Solartron Electronic Group of Thames Ditton in Surrey have now concluded selling and manufacturing licensing agreements for the *Kintel* range of electronic products of the Cohu Electronics Inc, of San Diego, California, USA, which covers the whole world, with the exception of Sweden and North and South America. They include d.c. digital voltmeter systems, d.c. data amplifiers, electronic galvonometers, digital readouts, electronic digital voltmeters, absolute d.c. power supplies, meter calibrators, d.c. voltage standards, strain gauge power supplies, microvoltmeters and ammeters, a.c. converters, accelerometers, and vibration and sound pressure measurement equipment.

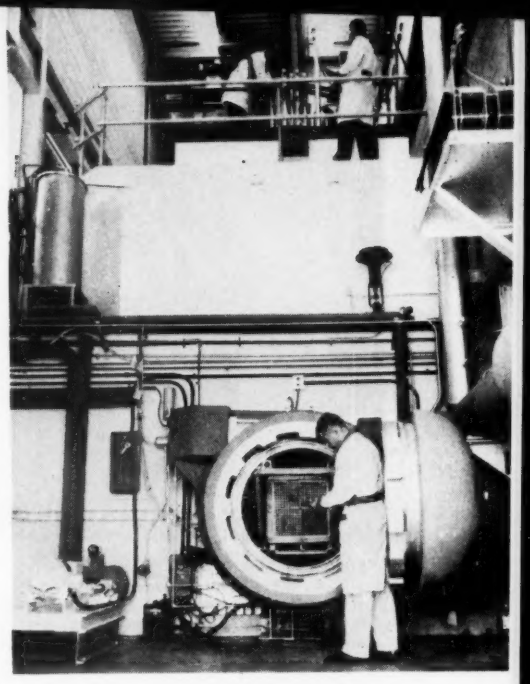
CEGB encourage high load factors

The Central Electricity Generating Board have announced their tariff for bulk supplies to be sold to the Area Boards in the year beginning April 1959. The new tariff will yield substantially the same revenue as if the present one were continued. But its make-up shows significant changes, continuing the trend established over the last few years.

The Bulk Supply Tariff for 1959/60 is made up of a maximum demand charge of £7 2s 0d per kilowatt (compared with the present £6) and a running charge of 0·41d per unit (compared with 0·46d). In addition, the coal cost adjustment of the running charge has been reduced to 0·00055d (compared with 0·0006d) for each penny by which the fuel cost per ton in the year shall be above or below sixty shillings.

The Tariff retains the modification to the fuel cost adjustment clause introduced in 1957/58 which enables importing Area Boards in relatively high fuel cost areas to benefit from imports of energy generated in relatively low fuel cost areas and transmitted in bulk over the Supergrid.

Subject to any unforeseen economic changes, the Board hope to avoid major alterations to this new bulk Tariff for the next three years: it is their hope that it will encourage improvement in load factor.



At the base of B & W's new pool reactor a fuel assembly is tested in an autoclave under simulated power conditions

Aircraft men switch

Aircraft and atomic energy work are going on side by side at the Vickers-Armstrong factory at South Marston, near Swindon. The factory, still completing Scimitar jet fighters for the Navy, has now set up a nuclear section employing about 100 physicists and engineers. Work in progress includes actual construction of two new experimental reactors for Harwell with another still on the board. Many of the staff were previously engaged on aircraft work and their conversion to nuclear is part of Vickers' plan to concentrate aircraft at their main Weybridge plant and turn the Swindon factory into a nuclear centre.

Graphite from Japan

Preparations are being made in Japan for starting the production of reactor-grade graphite. The Tokio firm of Showa Denko K.K. has announced that preparations are under way to start commercial production of 2000 tons a year to meet the anticipated demands for Japanese power stations and exports. Basic research has been completed and tests on the finished product carried out by the French, UK and United States atomic energy agencies.

Two grades of graphite are offered by the Japanese company—SMG moderator

HINKLEY BSD GEAR UNDER WAY Burst slug detection equipment for the Hinkley Point power station has already reached the prototype stage at Marconi's St Albans factory. The output of the ratemeter in the top of the cabinet is compared with a preset reference level by a count analyser below it which sets off alarms if the value is exceeded. The scanning and synchronizing system is located in the bottom of the cabinet

grade and SRG reflector grade. Mechanical properties are the same for both grades but the nuclear figures are as follows:—

		MODERATOR	REFLECTOR
Apparent density	g/cm³	>1·70	>1·70
Capture cross section	mb	<3·7	<4·5
Total ash content	ppm	<20	<500
Boron content	ppm	<0·1	<0·5

The graphite is manufactured either by extrusion or moulding and full machining facilities are available. Normal sizes of blocks are 4 in. square or 8 in. square but other sizes can be had on request. Showa Denko operate a graphite electrode plant manufacturing 12,000 tons a year. Much of this is exported to Europe.

AEI-JT move

On October 27 the headquarters of the AEI-John Thompson Nuclear Energy Co Ltd was moved to the new AEI building at 33 Grosvenor Place, London, SW1 (*tel:* Belgravia 7011).

Data logger for Westinghouse

A new data-logging system to be used at Westinghouse Electric's atomic energy test reactor in Pittsburgh was recently delivered by the Datex Corporation of Monrovia, California. It records on typewritten log forms and/or tape punch the magnitude of millivolt signals generated within seven reactor loop systems. These signals originate from a number of basic reactor variables under observation at critical points within these loops and include temperature, pressure, differential temperature and reactor power.

The firm reports that three new components—an input selector, an input programmer, and an alarm module—were developed for use in the new system. Flexibility is also reported to be a key feature. For example, the use of the newly designed components allows the order in which the input variables are selected to be completely flexible. Three different logging cycles are possible.

New computers on show

One of the most comprehensive displays of computers and peripheral equipment yet seen in this country has been arranged for the Electronic Computer Exhibition held at Olympia, London, from Nov 28 to Dec 4. Among the electronic digital machines making their first public appearance are the Elliott 802, Metrovic 1010, Powers Samas Pluto and the Ferranti Perseus. The first two are small transistorized jobs and power consumption of each is only 2kvA, which should reduce worries about wasting computer time. Magnetic core storage is 1020 words for the 802, and 2048 or 4096 for the 1010. Both can be used on scientific work, or with auxiliary equipment on process control and data processing systems. Transistors and printed circuits are also employed to some extent in the Powers Samas Pluto, a new large scale machine. Inbuilt storage capacity is over 8000 words using a magnetic drum and nickel delay lines. Speeds are high—addition for example takes ½ millisec and multiplication 2 millisec. Ferranti's, the first company to sell computers in the UK, offer their three machines: Pegasus, a general purpose computer, Mercury, tailor made for the nuclear industry, and the latest, Perseus, a big data processing system that markets at something like £300,000. Two items of peripheral equipment which should help the push towards higher speeds are a 3000 words a minute tapepunch by Creed & Co and a Rank-Xerox output printer which uses the xerography technique to print out at the rate of 3000 lines of 128 characters a minute.

BWRA develops pimple welding

Recently demonstrated at the open day of the British Welding Research Association, Abington, near Cambridge, a discovery in resistance welding, provisionally patented, is now being developed there. The discovery evolved

THE BACHELORS LIVE HERE To house unmarried scientists employed at the Dounreay Works the AEA has built this three-storey timber extension to the existing stone building. It was prefabricated by Simms Son & Cooke Ltd and Pyrolith treated to minimize fire risk

directly from work done at Abington for the UKAEA.

In spot welding, molten metal is expelled if the welding current is too high or if the electrode force is too low. This molten metal can be directed into a cavity in the welding face of an otherwise normal spot welding electrode. Since it freezes there to form a stud, strongly welded to the parent sheet, the technique is known as resistance casting, or sometimes as stud raising, or pimple welding.

Studs of highly varied shapes and sizes have been formed by this process in a wide range of metals, including steel, stainless steel, light alloys, titanium, and nickel alloys. A peg of similar or different material, inserted in the electrode cavity, can be cast into the stud; strong metallic bonding between the peg and stud can occur with compatible metals, though the purely mechanical joint formed with non-metallic pegs may also be strong.

New head for NPPC Research

On leaving Harwell (Worldview Nov) Dr H. M. Finniston is to take over the job of research manager at C. A. Parsons new nuclear research centre at Newcastle which handles all reactor research for the Nuclear Power Plant Co

TV for Merlin

Associated Electrical Industries Ltd has placed an order with EMI Electronics Ltd for a specially-designed underwater industrial TV camera for observation inside the MERLIN research reactor at Aldermaston. The camera is 30 in. long and 3½ in. in diameter and will be enclosed in a pure aluminium water-tight housing.

It will work in conjunction with a standard EMI camera which is being mounted on top of MERLIN to provide a continuous view all around the reactor and to ensure that no unauthorized staff are near the reactor when it is in use. Two ITM 14 viewing monitors will be rack-mounted in the reactor control room and a console monitor, capable of receiving pictures from both cameras, is being installed in the reactor conference room.

FIRST MOTOR CONTROLS FOR BRADWELL The initial batch of the £250,000 worth of motor control gear being built for the Bradwell nuclear power station by Brookhirst Switchgear Ltd leaves the company's Chester factory. Supplied under sub-contract to A. Reyrolle & Co Ltd, the equipment will incorporate 550 contactor-type starters for the centralized control of turbine auxiliaries and reactor essential auxiliaries, fuel handling plant, control rods and safety rods

US instrument exports

Shipments of nuclear radiation detection and measuring instruments from the US during July amounted to $187,626, according to Bureau of the Census figures just released. Breakdown as follows:—

Shipments valued $500 and over:	
Canada	21,464
Mexico	7,089
Colombia	7,266
Brazil	4,992
Sweden	8,600
United Kingdom	5,838
Belgium	5,108
France	16,985
West Germany	10,698
Austria	2,842
Switzerland	14,652
Finland	4,331
Portugal	10,000
Italy	8,891
Turkey	10,251
India	8,644
Japan	16,825
Algeria	800
Total	$165,276
Estimated shipments $100 to $499:	
3 Canada	5,870
7 Other	16,480
Total	$22,350

US Teleflex go nuclear

Creation of a separate nuclear division to handle rapidly increasing applications of its mechanical remote control systems is reported by Teleflex Inc. Named as manager of the new division is Eugene J. Mersa, Teleflex field engineer and nuclear control specialist. Some idea of Teleflex's interests is given in *New Product Survey* this month (p 602).

In brief

● **Pace for GEC** The European Division of Electronic Associates Inc announces the sale of its twentieth General Purpose PACE analogue computer since July 57—this time to the Atomic Energy Division of the General Electric Company, Erith.

● **Kelvin & Hughes Ltd** have opened new air-conditioned premises at their Barkingside works for the assembly of precision gyro and optical instruments.

● **N. Hingley & Sons Ltd** On November 5 chairman Cyril E. Lord started company's new ring rolling mill at Netherton, Worcs. It will produce light section rings up to 72 in dia. in ferrous and non-ferrous metals.

● **Midland Silicones Ltd** have announced a 10 pc reduction in the price of Silastic LS-53, a fluorinated silicone rubber for temperatures −60° to +200°C.

● **Valves** Mr J. W. Plowman (Dewrance & Co Ltd) has been re-elected chairman of the British Valve Manufacturers Association.

● **Solartron Electronic Group** are setting up new subsidiary in Sweden headed by Kurt P. Källgren. Similar companies are operating in Germany and Italy.

● **British Thomson-Houston Export** Co Ltd have moved to 33 Grosvenor St, London SW1 (Tel: Belgravia 7011).

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Book Reviews

Transistor primer

The Junction Transistor and its Applications edited by E. Wolfendale 1958: Heywood & Co 402 pp £4 4s

A collection of articles concerning only a few aspects of applications of junction transistors, this book seems largely based upon Mullard reports which have appeared previously. The work of nine contributors is included, and naturally the style and manner of presentation varies considerably. Also, since the sections are to some extent self-contained there is some overlap of subject-matter: for example the subject of transistor equivalent circuits is treated, with minor variations, on four separate occasions. There is divergence of opinion between the authors at times: thus the author of the first section (transistor physics) states that the reverse leakage current of a germanium *p-n* junction will double for an 8°C rise in temperature, whereas the author of the next section maintains that 9°C is the correct figure. If the matter is put to test by an independent calculation using the data and appropriate equations given in the book a figure of 7°C results.

However, despite such detail errors, the book contains much valuable material. In particular the first two sections (transistor physics and characteristics) give a clear picture of the characteristics of junction transistors and also bring out the underlying dependence of these characteristics upon the physics of semiconductors: an approach whose value has only recently been fully realized. Other chapters deal with equivalent circuits, biasing, A.F., H.F., and Class C amplification, oscillators, modulation and demodulation. These concern the bread-and-butter of the transistor world, namely, the sinusoidal market. These sections are, in the main, adequate, but are rendered rather tedious to read by the tendency of some of the writers to include each stage of the 'working out' of their algebra (surely unnecessary in a book of this standard), and also a plethora of numerical examples, again with each step in the calculations recorded in detail.

The chapter on non-linear circuits deals at length with some standard bistable and monostable circuits, binary counters and blocking oscillators, but digital computer techniques are not mentioned. Unaccountably the chapter fails to give any guide to what determines the response of a basic transistor circuit to pulse inputs, surely a matter of overriding importance with non-linear circuits. However in this case references are quoted for readers who wish to pursue the matter. The remaining chapters deal with d.c. convertors and transistor measurements.

As the transistor encyclopaedia, which its rather ambitious name suggests, the book falls short of the mark, However, if the title is disregarded, one finds, a good, although expensive, primer which should enable a newcomer to transistors to acquire a tolerable grasp of the more conventional applications.

A. R. Owens

This review originally appeared in CONTROL

Nuclear lexicon

Atomic Terminology Lore Lettenmeyer Munich 1958: Isar Verlag 298 pp Dm 24.80

English certainly seems to have become the master language of nuclear energy, if not of science as a whole. It was announced at Geneva that the only complete version of the Conference proceedings is to be published in English. Now we have this quadrilingual dictionary of atomic terminology in which the reference language is English with parallel translations into German, French, and Italian. Compiled by Lore Lettenmeyer, who works in the translation department of the European Iron and Steel Community, it sets out to provide 'a selection of the essential scientific terms used in atomic and nuclear physics, reactor engineering, radiation physics and associated fields.' English terms are listed in alphabetical order and numbered consecutively. There are alphabetical indexes in the other three languages giving the numbers these terms have in the main section.

In a spot check of several common and less common words the dictionary stood up pretty well and it should be a useful little book in the often onerous task of keeping up with the foreign nuclear literature.

Concise relativity

Special relativity for physicists G. Stephenson and C. W. Kilmister London, 1958: Longmans, Green & Co 108 pp Price 18s

With the many developments in modern physics requiring some knowledge of special relativity, there appears to be a need for a book which presents the theory in a detailed yet concise way without making heavy demands on its

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readers' mathematical ability. In this book no knowledge of tensor calculus is assumed and the theory is developed entirely in terms of three-dimensional vector analysis. It should be suitable for students reading for an honours degree in physics or mathematics and also for experimental physicists working in such fields as high energy particle accelerators, meson theory, and particle decay schemes.

Blowers made easy

Compressors and vacuum pumps and their lubrication The Shell Petroleum Co Ltd, London, 1958

Much more than its title would suggest, this book forms an excellent introduction to the theory and practice of compressors and vacuum pumps and is lavishly illustrated with line diagrams of typical machines. The section on compressors forms by far the largest portion and includes reciprocating, rotary positive-displacement and aerodynamic types. All these are described with particular reference to their lubrication.

By contrast the section on vacuum pumps is very much shorter but it includes a useful section on Apiezon products. Copies are available in the UK from Shell-Mex and BP Ltd, Shell-Mex House, Strand, London, WC2, and in other countries from the local Shell company.

Metallurgy in Europe

Symposium on special metallurgy Institut National des Sciences et Techniques Nucléaires Paris, 1958 : Presses Universitaires de France

Held at Saclay in June 1957, this two-day symposium was attended by nuclear and aeronautical metallurgists from several European countries. Papers covered a wide range of topics, including uranium growth under thermal cycling, allotropic transformations in uranium and iron, effect of irradiation on zirconium, and work on titanium, cobalt and aluminium.

Scaling up

The scaling-up of chemical plant and processes London, 1958 : Institution of Chemical Engineers 136 pp Price £3

This is the proceedings of a symposium held jointly in May 1957 by the Institution of Chemical Engineers, The Society of Chemical Industry, Het Koninklijk Institut Van Ingenieurs and De Koninklijke Nederlandse Chemische Vereniging. In addition to papers of general interest on scaling up there were several of special importance to the nuclear industry e.g. *Scaling-up of reactors from a knowledge of kinetics* by K. G. Denbigh, *Problems encountered in stirred slurry reactors by* J. V. van der Vusse, and *Scaling-up solvent extraction processes for irradiated nuclear fuels* by B. F. Warner. To members of sponsoring bodies copies are available at £2.

More for the layman

Atomic Energy Egon Larsen. London, 1958: Hennel Lock (Harrap) 196 pp Price 12s 6d

Trudging along a well-trod path Mr Larsen uses the reliable racy narrative style in describing for the layman how atomic energy was discovered and how it is being used. And he does it extremely well. The book is well illustrated and, in time, stops just short of the second Geneva Conference.

Books Received

Nuclear Reactors for Power Generation Ed. E. Openshaw Taylor 144 pp London 1958 : Newnes Price 21s

Disposal of Radioactive Waste K. Saddington and W. L. Templeton 102 pp London 1958 : Newnes Price 17s 6d

Radiation Counters and Detectors C. C. H. Washtell 114 pp London 1958 : Newnes Price 21s.

Radiations and Matter A. Berthelot (trans. F. R. Paulsen) 180 pp London 1958 : Hill Price 25s

The Nuclear Handbook Con. Ed. O. R. Frisch London 1958 : Newnes Price 50s

Symposium on Information Theory in Biology Ed. H. P. Yockey 418 pp London 1958 : Pergamon Price 80s.

NUCLEAR REACTOR PHYSICS

an elementary course

by JAMES F. HILL B.Sc. principal, Reactor School A.E.R.E. Harwell

In response to widespread demands, we have reprinted the course in basic reactor physics which was specially written for NUCLEAR POWER and published in serial form during 1956 and 1957. The monograph has been revised by the author and forms an excellent introduction. (64 pp. in stiff boards.) Price : UK, 30s + 1s 3d Abroad $5 + 20c or equivalent.

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The IAEA comes first

If any friction or duplication of effort occurs between the International Atomic Energy Agency and any other atomic energy organizations the United Kingdom will support the IAEA. 'We regard this agency as the predominant organization dealing with the peaceful uses of atomic energy and that will be the basis of our policy,' said Sir Edwin Plowden, chairman of the UKAEA, when he addressed the recent conference of the IAEA in Vienna. The UK wishes to see the Agency firmly established, taking its rightful place within the United Nations family, he went on. Satisfactory relationships with other international organizations will have to be worked out. Agreements with specialized agencies are welcomed but 'of necessity' they are in general terms and will need to be supplemented by continuing consultation to prevent friction and duplication of effort. Much can be done by friendly collaboration between the respective secretariats, but it cannot be left to the secretariats alone. The key to the matter is the policies of member states, and proper co-ordination inside the individual national administrations.

Supporting the IAEA against criticisms that it has moved slowly and achieved little, Sir Edwin said that no organization of such a scale could become fully operational within twelve months. Many of the technical staff did not take up post until March and at first there was bound to be a great deal of administrative work to do. There are now plenty of problems to be tackled by the Agency. An immediately useful step would be to get agreement on insurance to cover third party liability in the event of reactor accidents. Another would be regulations for the transport of radioactive materials by land, sea and air, and regulations for operation of nuclear propelled ships. There are the problems of disposal of radioactive waste, and the safe handling of radioactive isotopes; here the Agency has already formulated some useful rules. The problems cannot be tackled all at once, and, 'we must reach agreement on their proper order of priority,' he stressed.

Another and equally important field of the Agency's work is assistance to the less-developed countries. Last year the UK welcomed the proposed fellowship plan, and places have been found in British institutions for fellows nominated under the scheme. For some years now nearly half the students in the UKAEA's own schools have come from overseas countries. It is important that the training schemes should be linked with those aspects of nuclear energy and nuclear technology which can be applied in the immediate future. Radio-

SIR EDWIN PLOWDEN
They're doing all right

isotopes, for instance, can at once benefit almost every country whether developed or less developed. Research to develop new uses for isotopes can be undertaken partly by the Agency itself, and partly by the Agency in conjunction with national organizations.

No need for reactor plans yet

This sort of assistance, Sir Edwin thought, should take precedence over any scheme for supplying actual power reactors. No proposals for these are included in the Agency's programme at the moment and the decision has been criticized, but 'the fact is that nowhere in the world has a small reactor yet been designed to supply amounts of power appropriate to the needs of these less developed countries at an economic price. Small reactors that are economic will certainly be developed in time, but the scientific and engineering problems are formidable. Until solutions are in sight, the most useful help the Agency can give is to concentrate on what is practicable in the immediate future. In the meantime we need studies on the lines of Dr Bhabha's survey of Indian power requirements so that we can decide where nuclear power can be used most profitably. These must be made by the countries themselves or by the Agency on their behalf.'

Spurious trips are costly

'Nuclear instrumentation must be more reliable' was the—not unexpected—theme of B. H. Stonehouse's remarks on November 8 to a discussion panel of this year's SIMA Convention. A bull point of the Convention—held for three days at Harrogate under the new Presidency of Mr. R. Barrington Brock—was the presence of people from user industries, and throughout its sixteen sessions on facets of instrumenting major industries, speakers reiterated the need for user and instrument maker to collaborate.

Stonehouse, Senior Electrical Engineer of GEC's Atomic Energy Division, opened the discussion at the session given to nuclear plant instrumentation. He stressed the need for reliability in all instruments affecting reactor safety. A typical reactor had thirteen devices capable of tripping it; seven of these involved 'physical' measurements. Spurious trips cost about £10,000 each, and although triplicated instrumentation reduced the risk of these, greater instrument reliability was still wanted—especially for 'physical' measurements. He noted three development needs in instrumentation: less restrictive flow meters (for gas); CO_2 moisture meters measuring down to 100 parts in 10^6 with a response time of about 5 sec; and better data-reduction equipment. Instruments in contact with reactor coolant must be of materials compatible with coolant and canning material, and assembly must be in clean conditions. He ended by briefly discussing control rooms and differing ideas among the UKAEA, CEGB and nuclear station manufacturers on use of data-logging equipment.

Some points made in the general discussion—carried on by six 'users' and some thirty 'makers'—were that maintenance records of instruments should be available to their manufacturers; accelerated life tests are valuable in increasing reliability except for normally static instruments; soak tests of 50-100 hours on electronic instruments are useful; and instrument specifications admitting variations in voltage and frequency of supply of $\pm$10-20 pc militate against reliability. In one of several contributions, E. W. R. Little, of Distillers, pleaded strongly for instrument evaluation by a central authority. R. G. Davis, Ekco Electronics' Assistant Technical Manager,

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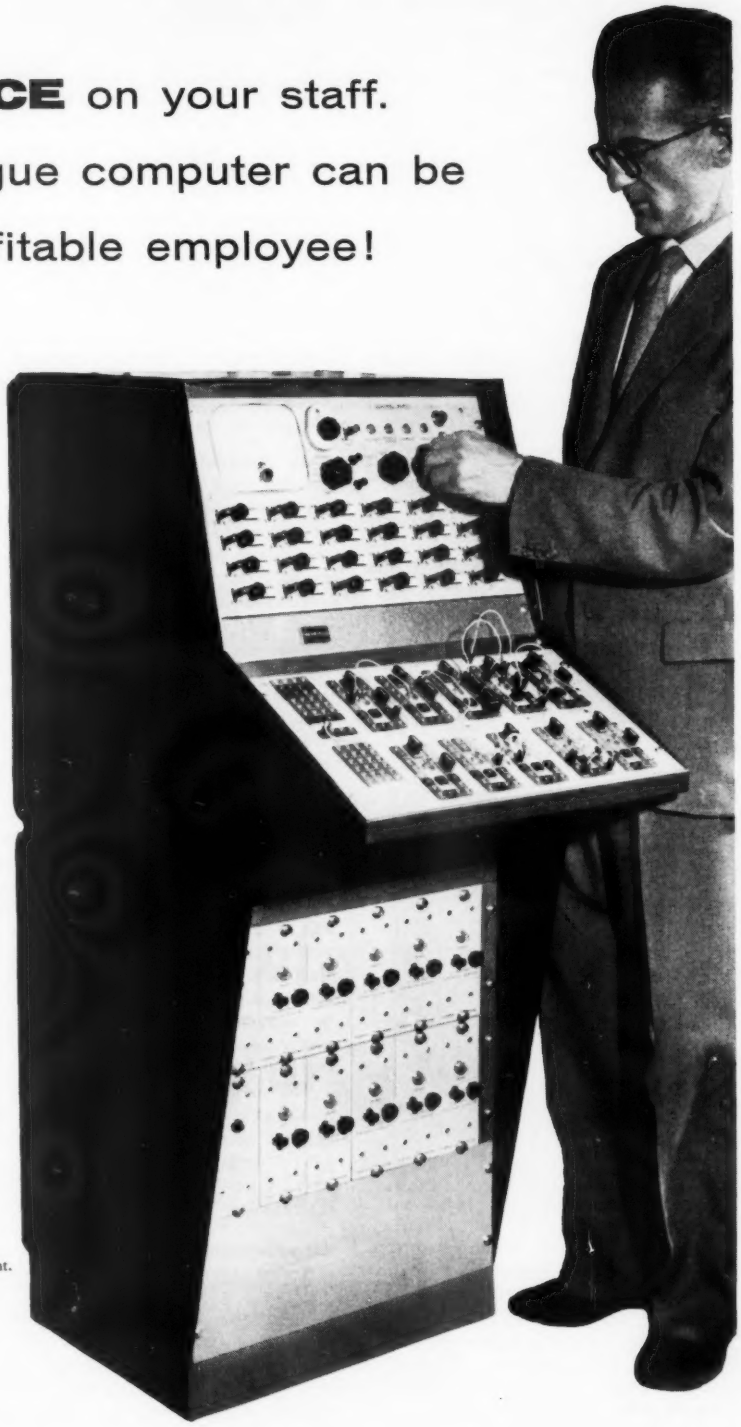

You, in common with every industry today, are facing more and more complex dynamic analysis problems — from simple differential equations to the simulation of industrial processes.

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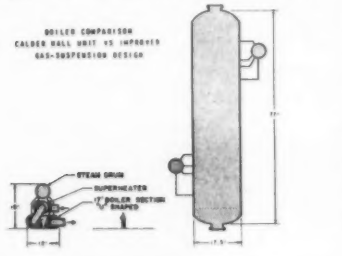
stressed the danger of inexperienced mechanics interfering with such electronic equipment as transistorized amplifiers. Stonehouse rounded off the discussion with a few words on future trends: one would soon need to measure higher temperatures in gas-cooled reactors—but these were unlikely to be outside the range of thermocouples used at present.

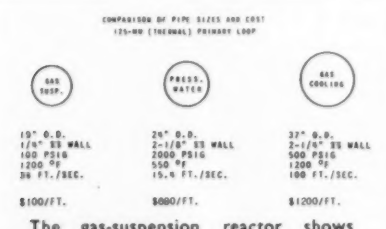
US reactor advances

A completely new method of reactivity control for water-cooled reactors and an important development in coolants for gas-cooled reactors were described recently by J. E. O'Connell, G. K. Rhode and D. C. Schluderberg of the Babcock & Wilcox Atomic Energy Division at Lynchburg, Virginia, during the official opening of the company's new pool reactor (see *Newsdesk* this month).

Spectral shift control

For 21 months, the B & W Atomic Energy division has been working on an advanced control method for water-moderated and cooled reactors. This method, which utilizes a mixture of





The gas-suspension reactor shows dramatic size and cost reductions

heavy and light water for the pressurized coolant-moderator, represents a logical extension of activity in connexion with the Consolidated Edison Thorium Converter Reactor and the Nuclear Merchant Ship (NS *Savannah*) reactor.

To achieve a core with a long lifetime it must be loaded with a quantity of fuel in excess of that basically needed to form a critical mass. This excess reactivity must be carefully controlled, and made available gradually to replace the material burned up.

In this new method, instead of using neutron-absorbing control rods to hold down the excess reactivity, the proportions of heavy and light water in the coolant-moderator are varied. The initial high concentration of heavy water (about 80 pc) requires more fissionable material for criticality than does the lower concentration (about 30 pc) used near the end of the core life. Consequently, a large amount of fissionable material can be safely loaded into the core at the outset. Then, as burnup proceeds, new fuel is made available effectively, by diluting the heavy water, since lower concentrations of heavy water require less fissionable material for criticality. In this manner, the energy spectrum of the neutrons is shifted, thereby controlling more reactivity over the lifetime of the reactor core. From this principle, the *Spectral Shift Controlled Reactor* gets its name.

Cost reduction The system offers the possibility of markedly reducing nuclear fuel costs by extending the reactivity life of a core to as much as 40,000 megawatt days per ton of fertile material, more than twice that expected from a conventional pressurized water reactor. Since this method of control also increases the average conversion ratio by about 0·2, fuel consumption costs in addition may be reduced by as much as 1 mill/kWh.

The reactor design also permits flexibility in choosing fuel cycles and fuel loading. For example, either thorium or U-238 can be used as fertile materials in either stainless steel or zirconium cladding. Additionally, since few if any control rods will be required, loading the fuel in non-uniform patterns will result in a more even power distribution and a higher average output can be extracted from a given core size. It is estimated that up to 75 pc more heat can be extracted through the use of non-uniform zone loading techniques with the new control method.

The major unsolved problems which make a preliminary development programme necessary are related to nuclear behaviour, operational control, radiation stability of the fuel element, and reconcentration of the coolant mixture.

Gas-suspension reactor

Recent research at B & W has shown that the heat transfer and heat transport properties of gases are greatly improved by suspending fine particles in the gases. The result is a low-pressure, low-cost reactor coolant which avoids many of the major design problems encountered with liquid coolants.

Preliminary studies indicate that this coolant will make possible the development of nuclear power plants which combine a high-temperature steam cycle with other factors important to the achievement of competitive nuclear power.

A gas-suspension reactor coolant will consist of fine particles (less than 5 microns) of graphite or other solids suspended in carbon dioxide, nitrogen, helium, or argon. The density of these mixtures will vary between 5 and 15 lb/cu. ft at an operating pressure of 100 psig or less. The coolant will be circulated in a closed primary system in an arrangement similar to primary systems for pressurized water, gas, or liquid-metal coolants.

B & W's work has been largely with graphite-CO_2 mixtures with densities up to 8 lb/cu. ft, circulated in a closed loop at 35 psig, 300 F, and 40 ft/sec. Loop operation has been very satisfactory with no evidence of erosion or significant particle adherence to surfaces. Heat transfer rate increased by a factor of eight over that for CO_2 at the same pressure, temperature, and velocity. In addition, the heat transported around the loop increased by a factor of 21.

Size reduction Effect of improved coolant characteristics is dramatically illustrated in the diagram. The remarkable size reduction anticipated for the gas-suspension unit will be due mainly to improved heat transfer and heat transport which will allow a marked reduction of total cooling surface. The improved heat capacity of the coolant will permit an increase in the reactor inlet temperature to 487°F (as compared to the 275°F inlet for Calder Hall) and eliminate the need for economizers and the two-pressure boiler system. Moreover, the possibility of extracting a higher temperature steam will result in a higher feedwater temperature and a significant improvement in steam cycle efficiency.

The expected reduction in size and cost of primary piping is equally impressive. The diagram also shows a comparison of sizes and costs of primary system pipes to transport 125 MW of heat. Coolant temperature rising through the reactors was assumed to be 600°F in an advanced gas-cooled reactor, 30°F in a pressurized water reactor, and 600°F in a gas-suspension system. Pipe diameters were chosen to give approximately the same pressure drop per foot of length. It will be noted that the cost of pressurized water and gas-coolant are 6 and 12 times greater, respectively, than the equivalent gas-suspension pipe, and are considerably larger in diameter.

Fuel, operating, and maintenance costs give every promise of being low since the coolant characteristics are favourable. Low pressure, good materials compatibility, and low neutron-capture cross-section combine to insure excellent neutron economy and trouble-free operation. It is estimated that a two-year programme will be required to complete the development of gas-suspension reactor coolants.

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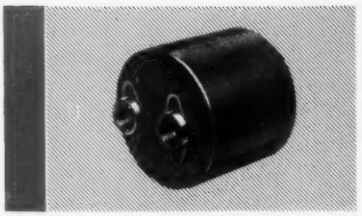

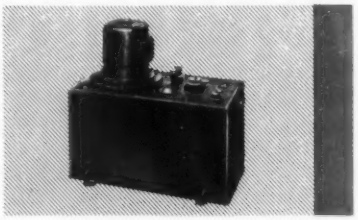

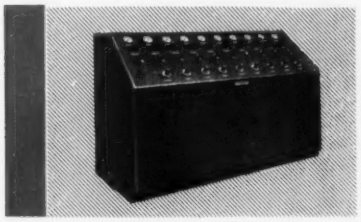

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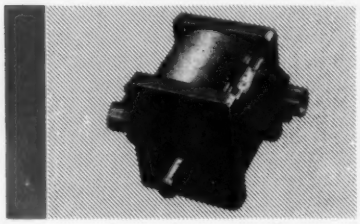
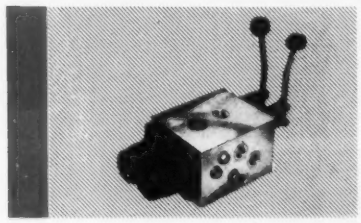
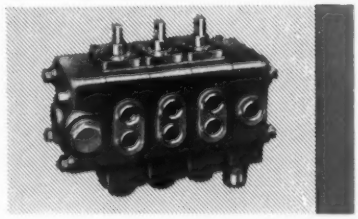
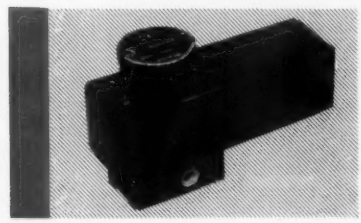


the greatest number of successful applications







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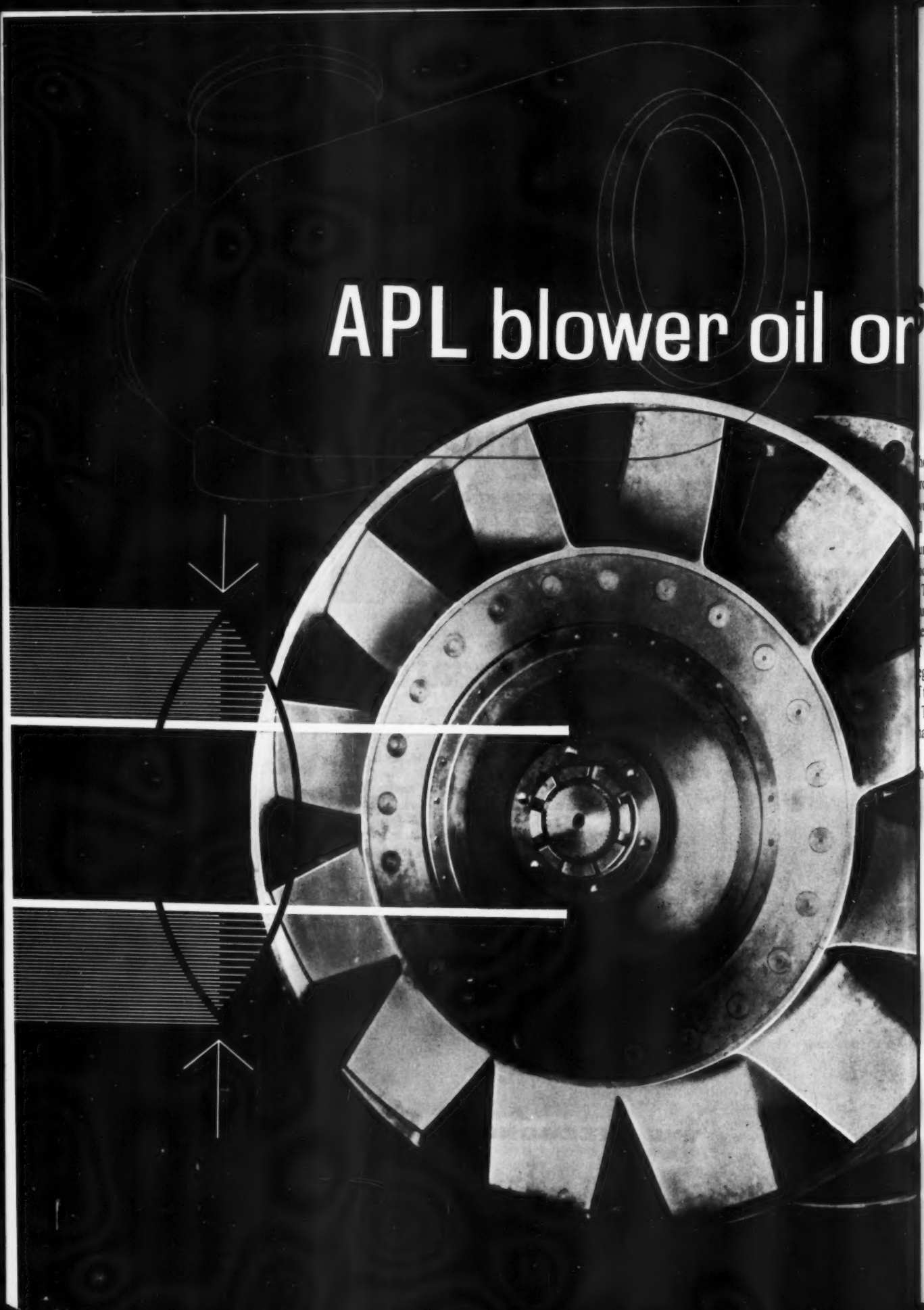


sentry-go at Bradwell...

he crucial points of the high pressure CO_2 coolant rcuit at Bradwell will be the blower shaft seals. ery minute of every working day Shell APL blower l will guard these escape points—being continually mped into the seals and bearings, led away, purified d recirculated.

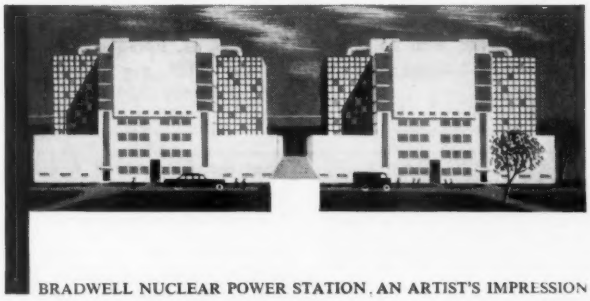
This very remarkable oil presents a two-way seal. twards, there is a minimum CO_2 loss as the oil has e lowest possible gas solubility. Inwards, in spite the heat of the gas, oil vapour contamination is egligible thanks to the extremely low vapour pressure the oil.

The research that went into APL blower oil is aracteristic of the way Shell set about doing things. was conducted at Shell's Research Centre at ornton in close collaboration with the U.K. A.E.A. and the blower manufacturers. In the course of much fundamental research, a wide range of oils was subjected to vapour pressure and gas solubility tests in the laboratory. Selected oils from this range were used in the bearings and seals of a blower rig. In 1956, after four years of research, the finished product joined the Shell Atomic Power Lubricants range—marketed under the name of Shell APL 729. This oil has been in use at Calder Hall since the autumn of 1956.

The moral of the story is that Shell research is supremely applicational. The Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubrication problem it pays to get in touch with your local distributor of Shell Industrial Lubricants.

The Research Story

Though the sealing action demanded of Shell blower oil is common in other industrial equipment such as hydrogen-cooled alternators, there were quite a few additional problems. It was necessary for the oil to have long life, low vapour pressure, low gas solubility, good thermal stability and h.gh film strength —to be able to withstand high temperatures and to be resistant to all kinds of corrosive influences, including carbonic acid. The crux of the research was to combine all the above requirements into one oil, in order to minimise back diffusion of molecules which would contaminate the reactor.



BRADWELL NUCLEAR POWER STATION, AN ARTIST'S IMPRESSION

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NAMES IN THE NEWS

President-elect of the British Institution of Radio Engineers for 1958–9 is **Professor E. E. Zepler** who occupies the chair of Electronics at the University of Southampton.

Mr C. R. Tottle, deputy director (reactors) at Dounreay has been elected a fellow of the Institute of Physics.

British Physical Laboratories have appointed **Mr D. J. Davis** as their sales manager. He succeeds **Mr D. G. Ashton Davies** who will be joining EMI Electronics Ltd.

The Accurate Recording Instrument Co announce the appointment of **Mr H. S. Parslow** as sales organizer and manager.

Mr D. E. Burton has joined Rocol Ltd, lubricant manufacturers, to be in charge of their London technical sales department.

Mr G. C. R. Eley has joined the board of The British Oxygen Co Ltd.

Babcock & Wilcox Ltd have appointed **Mr J. H. Prole** as assistant manager of their mechanical handling division.

Professor S. Pippard has assumed office as 94th president of The Institution of Civil Engineers.

The CEGB recently made the following appointments. **Mr R. Farrall** becomes services engineer and **Mr T. A. G. Madden** will succeed him as production, inspection and test engineer.

Sir Donald Bailey (well known as the designer of the Bailey Bridge) has been co-opted to the Council of the British Welding Research Association.

Mr R. F. Webb, a former Cambridge lecturer, has joined the firm of Ciba (ARL) Ltd where he will direct research work on new plastics.

The UKAEA have appointed **Mr J. A. Gay** to be their patents exploitation officer in succession to **Mr T. Benson Gyles.** Mr Gay was previously in the Industrial Group's commercial department at Risley.

Mr A. H. Hird has relinquished his directorship of Vickers - Armstrongs (Engineers) Ltd.

Mr J. N. Toothill, general manager of Ferranti's Edinburgh factory has been made a director of Ferranti Ltd.

As from January 1 **Mr J. N. B. Alexander** and **Mr S. W. Kaye** will be joint managing directors, sales, of Stewarts & Lloyds.

Mr G. M. Baker a director of C. A. Parsons and Co has been made general manager.

Mr F. N. Sutherland and **Mr Paul de Laszlo** have been elected to the boards of Marconi's Wireless Telegraph Co Ltd and Marconi Instruments Ltd. Mr Sutherland becomes managing director of Marconi's Wireless Telegraph Co Ltd.

The note on **Mr Gresley** of Gresham Transformers last month we are now informed is misleading. Mr Gresley is head of the power and distributor transformer division of the company, a division which has been in existence since 1938.

OBITUARY

We record with regret the following deaths.

Mr E. W. Steele, a former director and general manager of works of Metropolitan-Vickers Electrical Co Ltd died on October 7.

On September 9 the death occurred of **Mr C. C. Mason** at one time a joint managing director of Cambridge Instrument Co Ltd.

Mr E. M. Johnson, before his retirement chief engineer of Metropolitan-Vickers Electric Co's plant department (large electrical machines).

Mr B. E. G. Forsling who was manager of the BTH gas turbine engineering dept at Rugby died on October 23.

G. C. R. ELEY

J. A. GAY

J. N. TOOTHILL

E E. ZEPLER

CATALOGUES AND BULLETINS

Specification for an electric sequence recorder has been issued by Jones, Tate & Co Ltd. Distributor is available for controlling 12, 18 or 24 units.

Tick **No 218** on reply card

M.S.4, a silicone compound for insulating and waterproofing, made by Midland Silicones Ltd is described in a leaflet from the distributors: Holiday & Hemmerdinger Ltd.

Tick **No 219** on reply card

Monograph No 36 from Hopkin & Williams Ltd is by E. J. Newman on *p*-Bromomandelic acid, a reagent for Zirconium.

Tick **No 220** on reply card

Ventilation handbook from Colt Ventilation is well illustrated with photographs and has several pages of elevations showing where various types of ventilation are suitable.

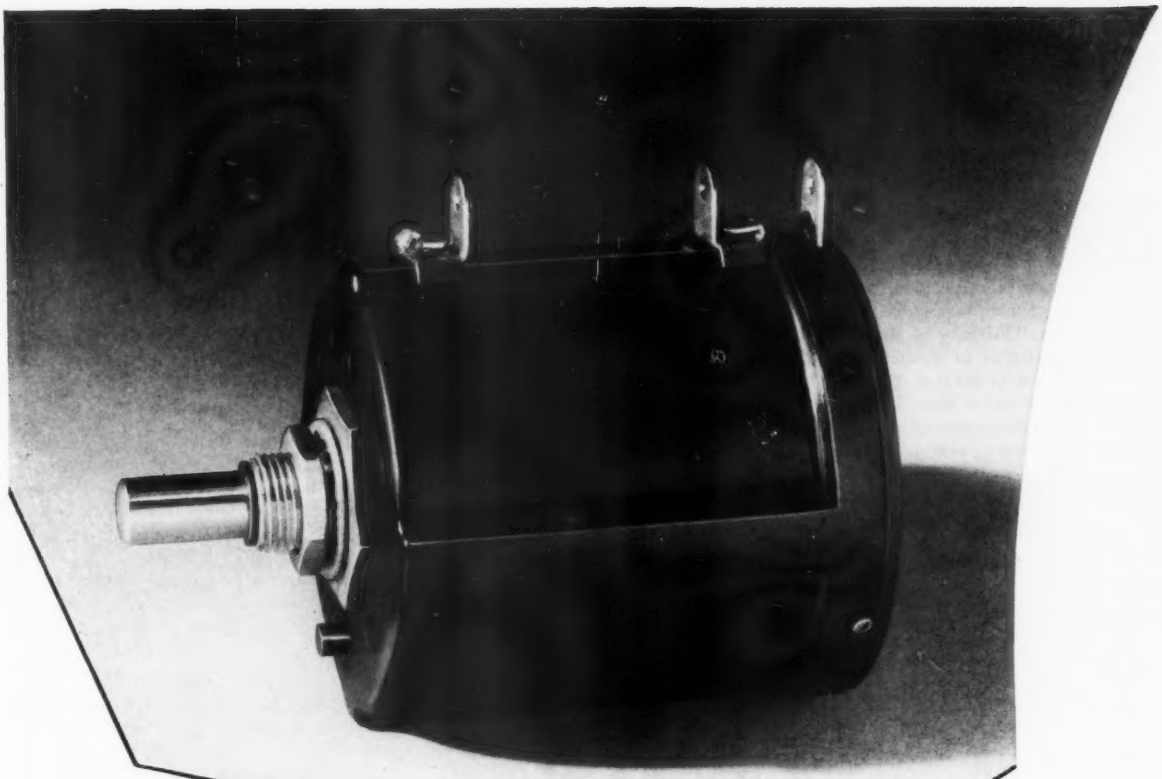
Tick **No 221** on reply card

Technical data sheet giving physical and chemical properties and applications on nuclear and commercial-grade zirconium hydride can be had from Metal Hydrides Inc. of Massachusetts.

Tick **No 222** on reply card

Measuring and controlling nuclear energy is the title of a new and attractively illustrated book recently brought out by George Kent Ltd, which shows the many and varied uses of their instruments in atomic energy work.

Tick **No 223** on reply card



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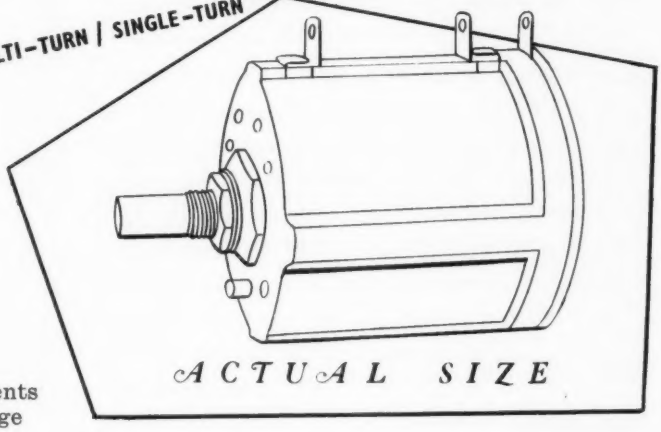

ACTUAL SIZE

with all the experience of the Helipot Division of Beckman Instruments Inc., behind them, Beckman Instruments Limited are manufacturing a range of Helipots and Counting dials at their new factory in Scotland. For full details contact

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NEW IDEAS

nucleonic patents

Disposal by irradiation

To overcome the problem of disposal of radioactive fission products, this patent suggests exposing them to radiation to convert them into stable or short-lived isotopes. This may be done either in an accelerator or in a reactor e.g. in the fuel rods or moderator of a heterogeneous reactor or in pipes or the control rods in a homogeneous one. Where possible an energy-yielding reaction is chosen. Separation of the resulting isotopes may be done by physical, chemical, or physicochemical methods if they are in the same phase as the residue, or by filtration, decantation etc if in a different phase.

Typical reactions suggested are:

$^{85}Sr + n \rightarrow {}^{86}Sr$
(65 d) (stable)

$^{207}Bi + n \rightarrow {}^{103}Ru + {}^{105}Ru$
(50 y) (40 d) (4·4 h)

$^{204}Tl + {}^{4}He \rightarrow {}^{209}Tl \xrightarrow{e^-} {}^{208}Pb$
(2·7 y) (3·1 m) (stable)

802,971 Process for the destruction of radioactive residues *Louis Verchraeghen* Appn: Jan 27, 1956 Pubd: Oct 15, 1958

Nb_2F_5 as coolant

Union Carbide suggest using niobium pentafluoride as a reactor coolant. Its great advantage is that, while solid at room temperature, its melting point is 80°C and it boils at 234·9°C. Its latent heat of vaporization is 12·9 kilocalories and since it changes state at the temperature of the reactor, a small volume of it will absorb a large quantity of heat. No pumping is required because the vapour rises upwards into the heat exchanger, is condensed and flows back into the bath.

802,938 Improvements in the cooling of nuclear reactors *Union Carbide Corp* Appn: July 1, 1955 Pubd: Oct 15, 1958

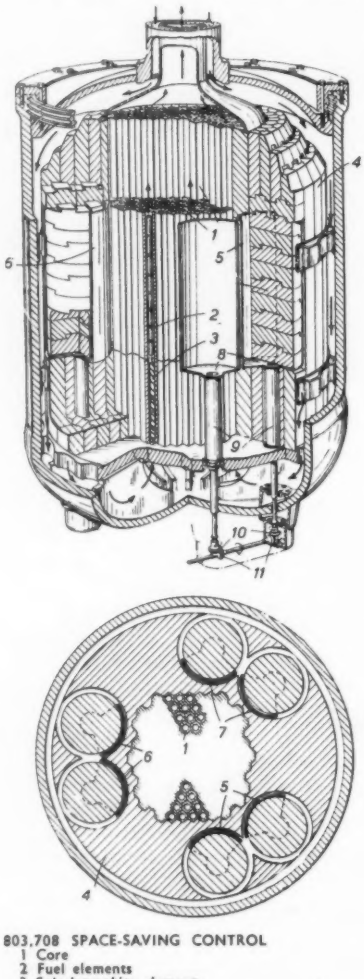
Fluid control

This is a control system with no moving parts, performing the functions of shut-down and power control, and a means of adjusting flux distribution. It comprises tubes in the core filled with a neutron absorbing fluid, formed of a variable mixture of two components. Fluid is supplied to the reactor tubes from a main reservoir by a pump to a constant head mixing tank. After adding either constituent as required, the fluid is circulated through the re-entrant core tubes. A suitable fluid is an aqueous solution of a cadmium salt.

803,701 Improvements in and relating to nuclear reactors *C. A. Parsons & Co Ltd* (Inventors: A. T. Bowden and E. Smart) Appn: Aug 11, 1955 Pubd: Oct 29, 1958

Rotary control shields

The advantage of the reactor control system proposed here by Rolls-Royce is space saving because the control elements do not protrude from the reactor when removed. In the graphite-moderated, helium-cooled reactor illustrated they are of part-cylindrical form—say an arc of 120°C and radius of half the minimum reflector thickness—mounted to move in a circular path in the graphite. They can equally well be complete drums with a neutron absorber attached to part of the surface. In the position shown the cylinders (5, 6, 7) act as neutron absorbers and, when rotated about their axis to the opposite position, act as reflectors. Grouped in pairs, each element is mounted on a quadrant attached to a spindle (9) carrying a bevel gear (10) and each pair is driven by meshing bevels (11) on a common shaft. Both elements of a pair are operated together, moving in angularly opposite directions.



803,708 SPACE-SAVING CONTROL
1 Core
2 Fuel elements
3 Spiral graphite elements
4 Reflector
5, 6, 7 Control elements
8 Quadrant
9 Spindle
10 Bevel gear
11 Meshing bevels

803,708 Improvements in or relating to nuclear reactor control mechanism *Rolls-Royce Ltd* Appn: Dec 31, 1956 Pubd: Oct 29, 1958

In brief

To reach the high bulk density **uranium dioxide** necessary for use in reactors i.e. 9·5 g/cc or more, cold pressed masses of the dioxide comprising non-stoichiometric phases are sintered in an inert atmosphere at 200 to 1·500°C for half an hour or more. Method of doing this and of preparing the defective structure uranium dioxide is described in the UKAEA's specification 801,381.

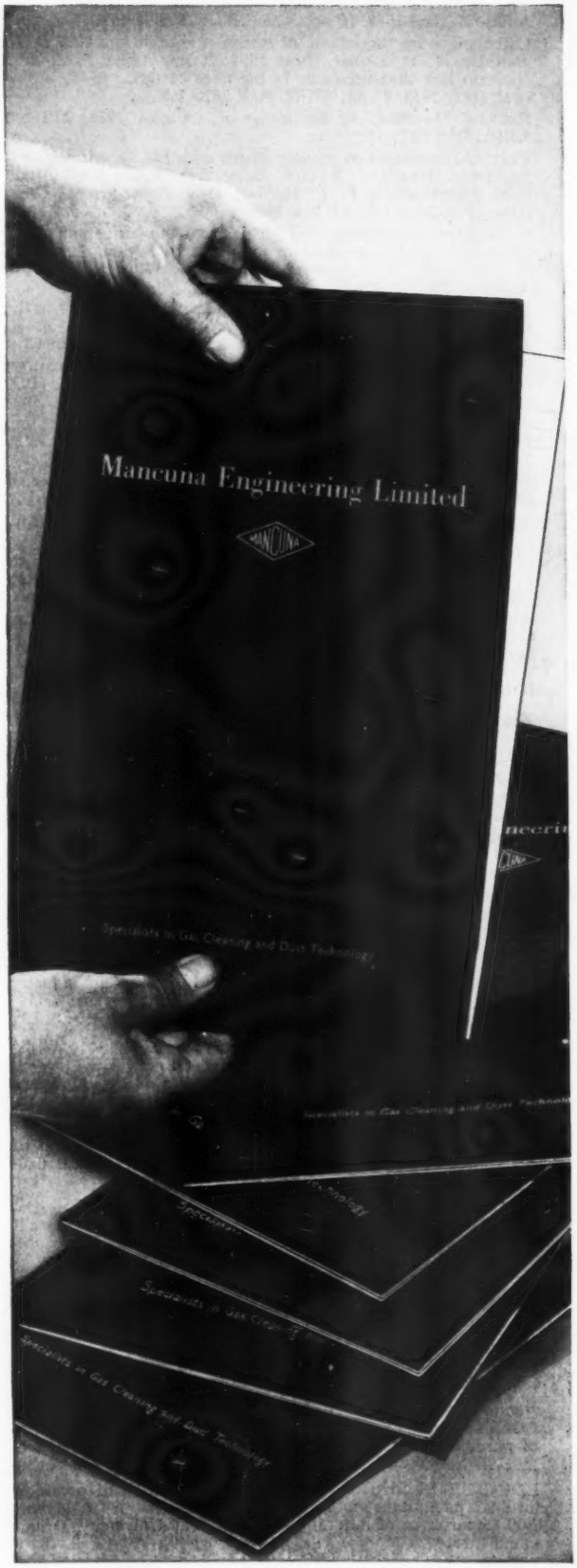
Applied for in Canada twelve years ago, 801,651 is for a reactor with a natural uranium graphite core of **subcritical size** and control rods containing at least 1·5 pc by weight of fissionable material. As the reactivity decreases, the rods are inserted further and further into the pile so that there is no intentional waste of neutrons at any stage in the operation. Obviously applicable to fast breeders.

For use with both light and heavy water cooled reactors, a **fpd system** by Atomic Energy of Canada is detailed in 793,297 in which only fission products emitting neutrons are detected. Monitor is placed near coolant outlet duct at a sufficient distance from the reactor for neutron-emitting substances likely to give rise to spurious readings to have decayed.

Two consecutive numbers from Babcock and Wilcox (802,805 and 802,806) cover the design of an aluminium-clad **fuel element and sheath.** The first describes spacers between the rod and can comprising groups of radial pins attached either to the element or the can. In the second a similar arrangement for the sheath is outlined to keep it central in the reactor channel.

To allow sufficient volume in the pressure vessel to contain radioactive gases resulting from a leak, RCN propose in 803,569 the use of an **expanding gas holder** in their suspension type reactor. Preferably a wet gasometer, this is attached to the shell via a condenser which reduces the expanded volume by removing vapours and also enables costly liquids used in the system—such as heavy water—to be recovered.

These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications can be obtained from the Patent Office (Sales Branch), 25 Southampton Street, London, W.C.2. 3/6 a copy (including postage, inland and abroad)



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Reports are also available in the United States, from the USAEC depository libraries, a list of which will be found in NUCLEAR SCIENCE ABSTRACTS. Reports for sale may be purchased in the United States from: Sales Section, British Information Services, 30 Rockefeller Plaza, New York 20, N.Y.

AERE Harwell

Colorimetric determination of plutonium in microgram quantities. *T. V. Healy, P. E. Brown.* (Nov 1953. 16 pp) AERE C/R 1287 4s*

Selected abstracts of atomic energy project unclassified report literature in the field of radiation chemistry and bibliography of the published literature. Second annual supplement. (Papers noted up to Dec 1957.) *R. W. Clarke.* (1958. 330 pp) AERE C/R 1575 (1 to 6) Supplement 2 42s*

The experimental determination of conversion factors and fast fission factors. *C. G. Campbell, M. D. Carter.* (1958. 7 pp) AERE R/R 2397

A remotely-operated polarographic apparatus. *C. Jackson* (August 1958. 10 pp) AERE ES/R 2491 2s 6d*

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Interdiffusion behaviour of copper and uranium. *I. J. Bear, A. D. Le Claire.* (June 1951. 19 pp) AERE M/R 2544 4s 6d*

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Flux and cross-section measurements with fast fission neutrons in BEPO and DIDO. 1. Relative fission flux profile. 2. (n,p) and (n,α) cross-sections. *C. E. Mellish, J. A. Payne, R. L. Otlet.* (July 1958. 20 pp) AERE I/R 2630 3s 6d*

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An absolute measurement of the effective delayed neutron fraction in the fast reactor ZEPHYR. *D. B. McCulloch.* (July 1958. 9 pp) AERE R/M 176

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The United Kingdom atomic power programme. A selected reading list. *N. Skeats.* (July 1958. 9 pp) AERE Reading list 2.

A list of British books and periodicals on atomic energy. *N. Skeats.* (July 1958. 21 pp) AERE Reading List 3

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A selected reading list on controlled thermonuclear reactions. *C. Sabel.* (August 1958. 5 pp) AERE Reading List 5

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Equipment for the machining and tensile testing of irradiated uranium. *D. Shaw, W. G. Hufton.* (1958. 8 pp) IGR TN/W 905 3s*

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ICE Institution of Civil Engineers. IMechE Institution of Mechanical Engineers. IEE Institution of Electrical Engineers. IChemE Institution of Chemical Engineers. IP Institute of Physics. PS Physical Society. SCI Society of Chemical Industry. IM Institute of Metals. IMet Institution of Metallurgists. IMM Institution of Mining and Metallurgy. IPE Incorporated Plant Engineers. SIT Society of Instrument Technology. BritIRE British Institution of Radio Engineers. RSH Royal Society of Health. IR Institute of Refrigeration.

TUESDAY 2

MANCHESTER IEE Thermonuclear fusion and the development of ZETA *E. R. Hartill* 6.15 Engineers' Club, Albert Square

WEDNESDAY 3

SOUTHSEA IPE Safety in the use of electricity *S. J. Emerson* 7.30 at Royal Beach Hotel

THURSDAY 4

MANCHESTER BritIRE High input impedance d.c. amplifiers *S. Stuart* 6.30 Reynolds Hall, College of Technology, Sackville Street

LONDON IEE (with BNEC) A review of work towards nuclear energy from controlled thermonuclear reactions *D. W. Fry* 5.30 at the Institution

FRIDAY 5

LONDON IMechE (with BNEC) An experimental investigation into the stress distribution in a band reinforced pressure vessel *K. G. Mantle, N. Marshall, P. J. Palmer* 6.00 at the Institution

MONDAY 8

SHEFFIELD IPE Argon-arc welding of corrosion and heat resisting steels *J. A. McWilliam* 7.15 at Grand Hotel

NEWCASTLE IEE Electrification of the UKAEA industrial group factories *J. W. Binns, W. J. Outram* 6.15 Neville Hall, Westgate Road

TUESDAY 9

MANCHESTER IPE Application of hydraulics in industry *J. R. Fawcett* 7.15 at Engineers' Club, Albert Square

LONDON SCI Some aspects of radiation induced chemical process *Dr R. Roberts* 6.00 at SCI headquarters

LONDON ICE The use of radioactive isotopes for the investigation of sewage treatment plant *S. G. Burgess, A. F. Green* 5.30 at the Institution

WEDNESDAY 10

LLANDAFF BritIRE AGM and discussion: the training of electronics and radio engineers 6.30 Llandaff Technical College

THURSDAY 11

GLASGOW IPE Can formal management techniques benefit the work of the plant engineer *F. R. Curry* 7.15 at the Scottish Building Centre, 425 Sauchiehall Street

LONDON IPE The European common market—its origins and implications *Sir Cecil Weir* 6.30 at the Royal Institution, Albemarle Street. Admission by ticket only

FRIDAY 12

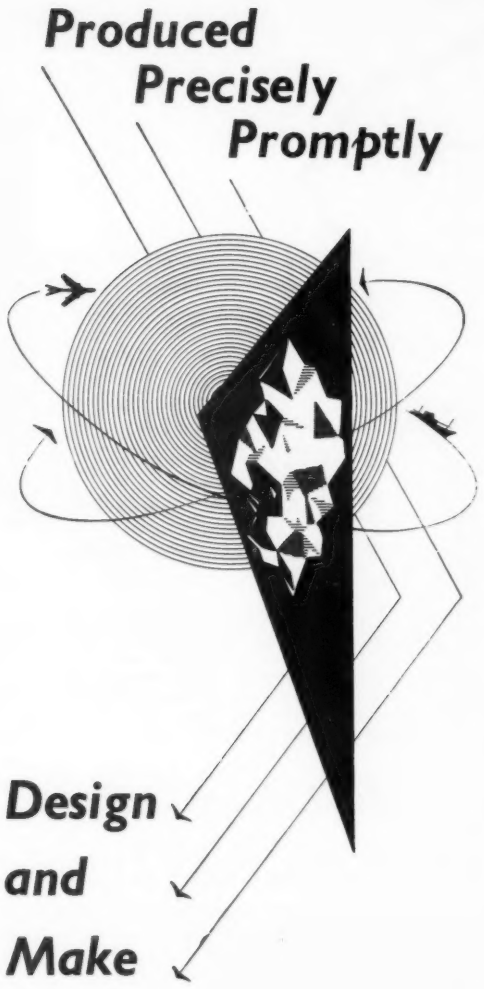
LONDON IMechE Discussion: boiler and component trouble 6.00 at the Institution

WEDNESDAY 17

ROCHESTER IPE Treatment of trade effluents and methods of purification *T. Waldmeyer* 7.00 at King's Head Hotel

FRIDAY 19

EDINBURGH BritIRE Design and construction of precision toroidal potentiometers for data transmission *H. J. Arnott* 7.00 Department of natural philosophy, The University, Drummond Street



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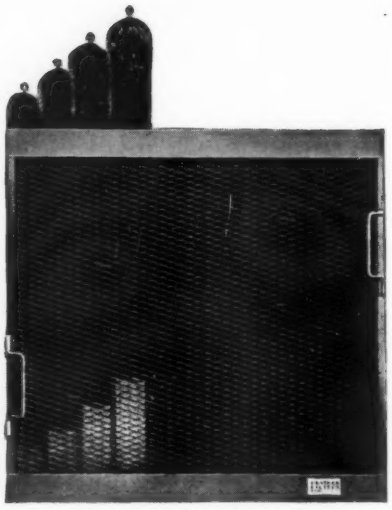

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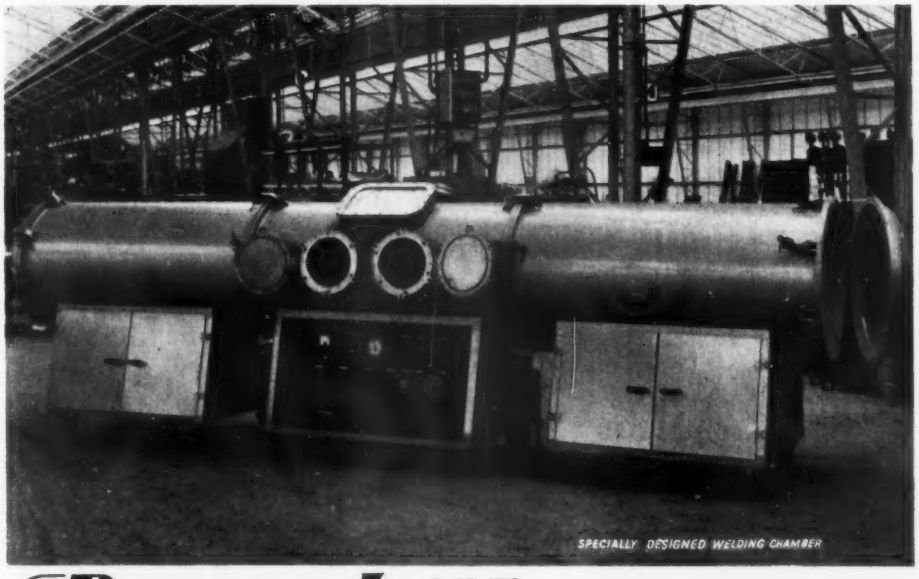

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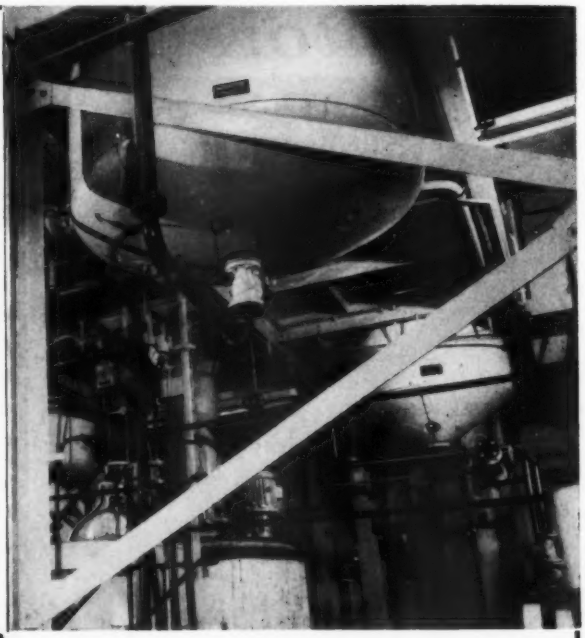

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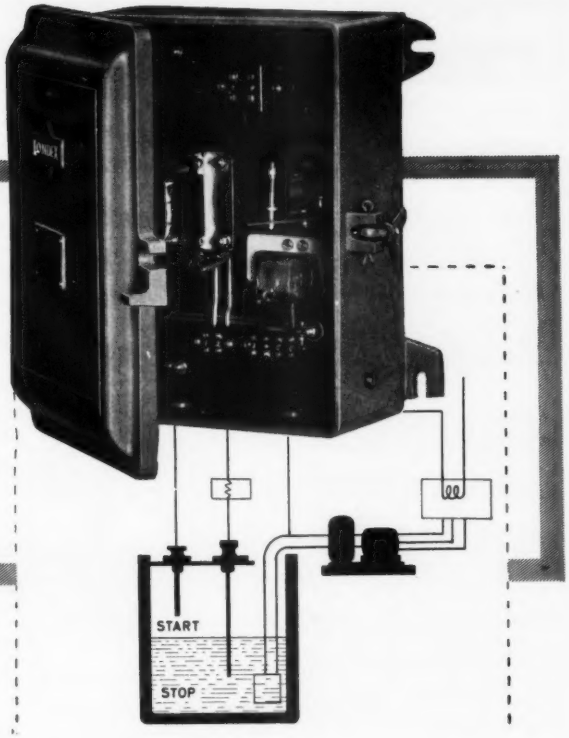

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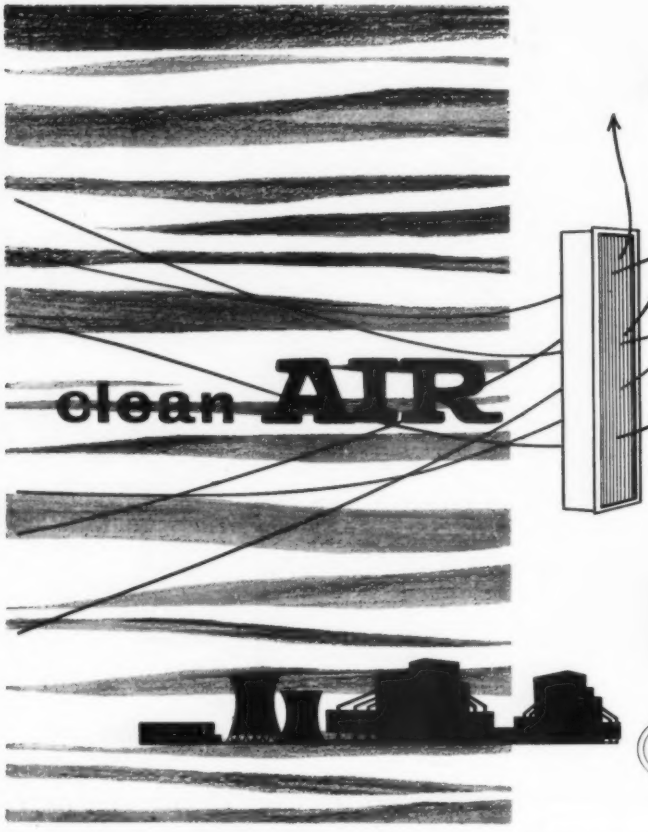

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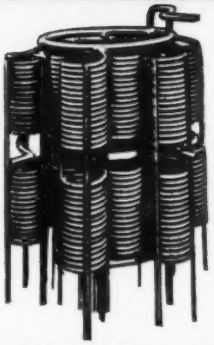

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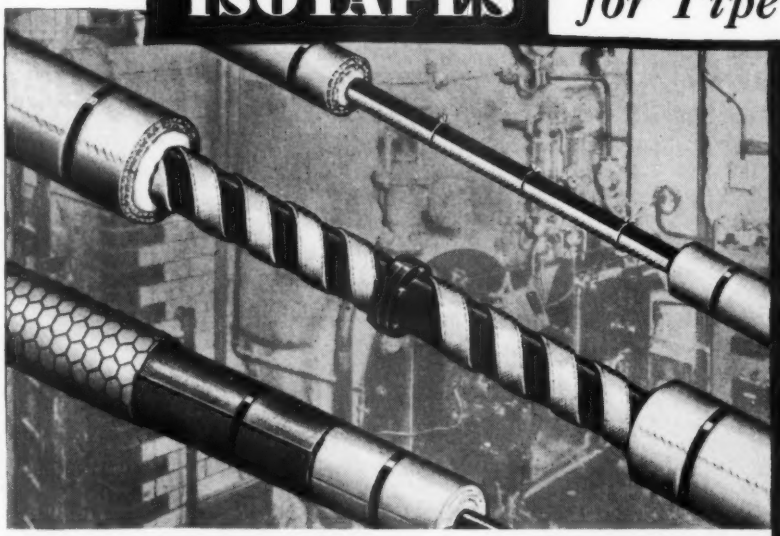

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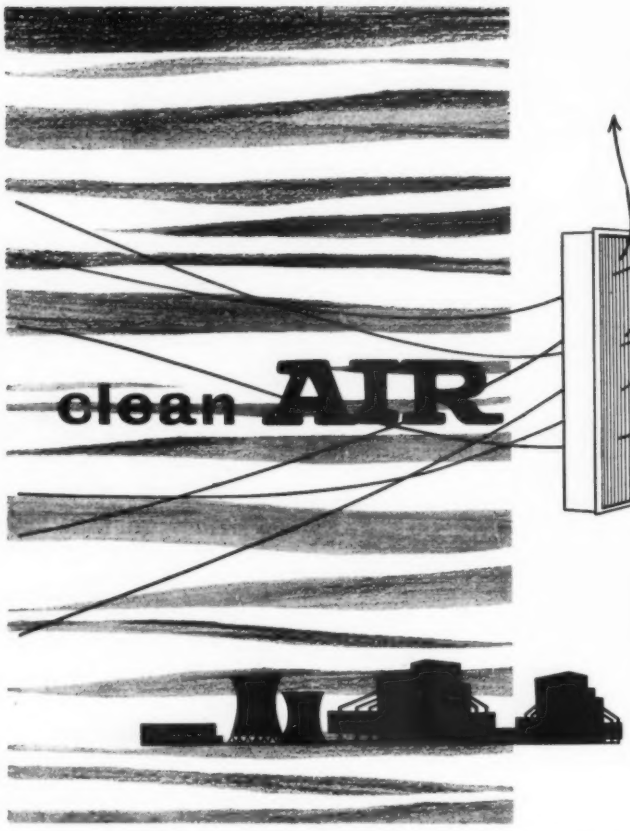

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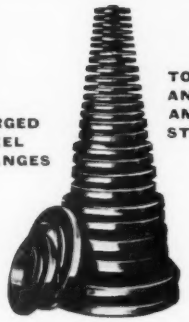

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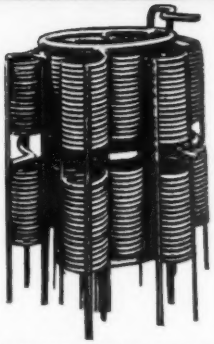

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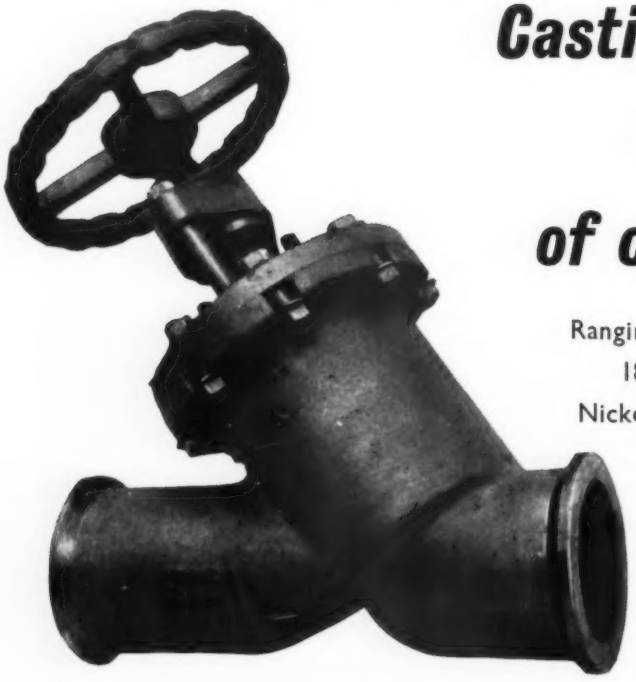

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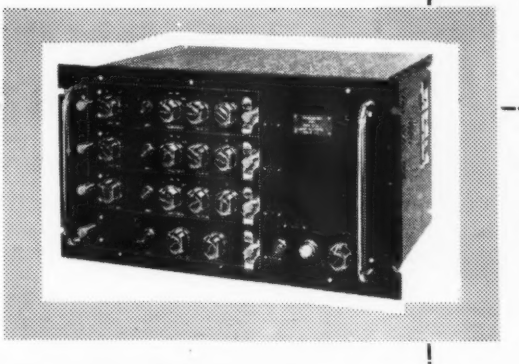

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I Channels 1 and 2 in coincidence.
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III Channels 1 and 2 in coincidence, the output being in anti-coincidence with channel 3.
IV Channel 3 in coincidence with channels 1 or 2.
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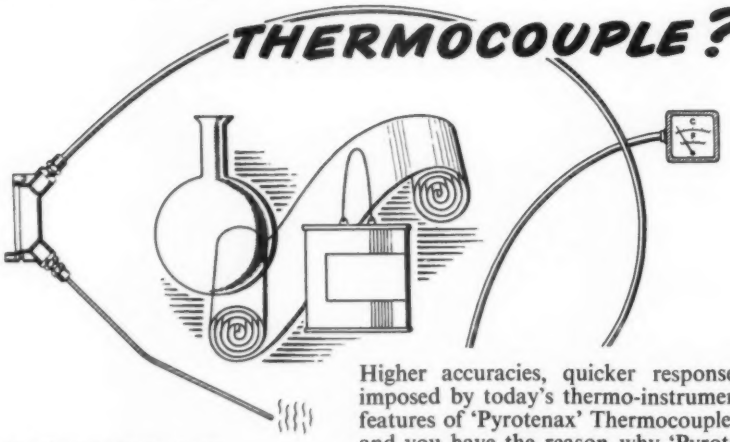

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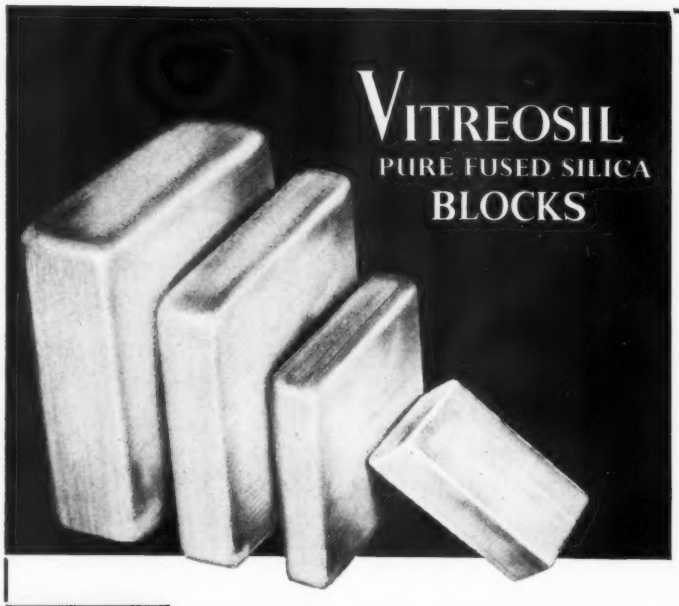

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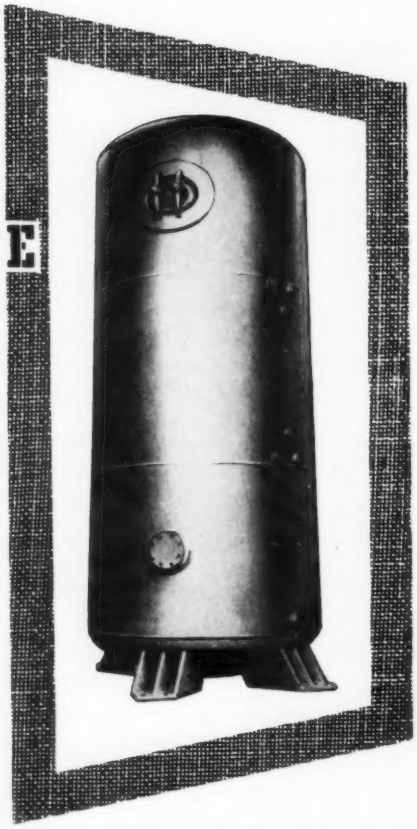

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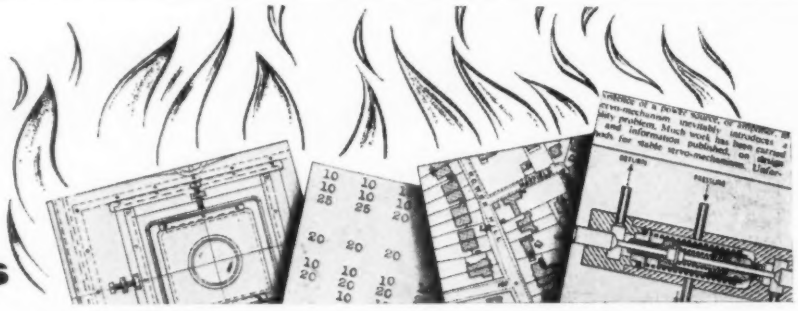

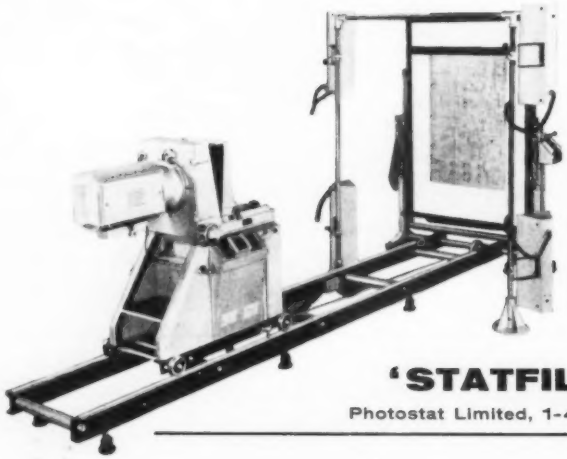

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- ☐ Pollard Bearings Ltd A45
- ☐ Hoffmann Mfg Co Ltd A76

Carbon and Graphite
- ☐ Morgan Crucible Co Ltd, The A26

Chemicals and plastics
- ☐ Grace & Co, W. R. A79
- ☐ Imperial Chemical Industries Ltd A25, A29
- ☐ Nash & Thompson Ltd A67

Construction, design and allied services
- ☐ Screw Machine Products Ltd A77

Electric motors and gear units
- ☐ Electrical Power Eng Co (Birmingham) Ltd A72

Electrical generating and subsidiary equipment
- ☐ Fraser & Fraser Ltd A74

Fans, ventilators and air conditioning equipment
- ☐ Keith Blackman Ltd A24
- ☐ Morris Ltd, B. O. A65

Filters
- ☐ Endecotts (Filters) Ltd A79
- ☐ Heather Filters Ltd A58
- ☐ Ozonair Eng Co Ltd A62
- ☐ Vokes Ltd A19

Gas treatment, movement control and storage
- ☐ Evans & Sons (Wolverhampton) Ltd, J. A59
- ☐ Imperial Chemical Industries Ltd A15

Heating plant and equipment
- ☐ Electrothermal Eng Ltd A60
- ☐ Isopad Ltd A63
- ☐ Pyrotenax Ltd A68
- ☐ Standard & Pochin Bros Ltd, The A78
- ☐ Thermal Syndicate Ltd, The A69

Industrial films, books and exhibitions
- ☐ Blackwells 612
- ☐ Energia Nucleare A83
- ☐ Heffers of Cambridge 612
- ☐ Mancuna Eng Ltd 623
- ☐ Nuclear Reactor Physics 613
- ☐ Turners Film Productions A49

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- ☐ Airmec Ltd A10
- ☐ Avo Ltd A73
- ☐ Bailey Meters & Controls Ltd A9
- ☐ EMB Co Ltd A12
- ☐ British Rototherm Co Ltd A76
- ☐ Burgess Products Co Ltd A30
- ☐ Davison & Co (Hexham) Ltd A76
- ☐ Dynatron Radio Ltd A65
- ☐ Imhof, Ltd, Alfred A32
- ☐ Inglis Knibb & Co A80
- ☐ KDG Instruments Ltd A68
- ☐ Keelavite Hydraulics Ltd 617
- ☐ Londex Ltd A61
- ☐ Lyons Ltd, Claude A66
- ☐ Research & Control Instruments Ltd A3
- ☐ Sangamo Weston Ltd A1
- ☐ Sealey Eng Co Ltd A73
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- ☐ Solartron Electronic Group Ltd 615
- ☐ Stonebridge Electrical Co Ltd A80
- ☐ Sunvic Controls Ltd A35
- ☐ Taylor, Taylor & Hobson Ltd A4
- ☐ West Instruments Ltd A75
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- ☐ Winston Electronics Ltd 621

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- ☐ Cape Asbestos Co Ltd, The A21
- ☐ Kenyon & Sons Ltd, William A50
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- ☐ Erhard, Johannes A44
- ☐ Evans & Sons (Wolverhampton) Ltd, J. A59
- ☐ Hayward Tyler & Co Ltd Cover 4
- ☐ Hopkinsons Ltd A34

Lubrication
- ☐ Shell-Mex & BP Ltd 618, 619

Mechanical handling
- ☐ Morris Ltd, Herbert A27
- ☐ Moore Ltd, W. & E. A67
- ☐ Paterson Hughes Eng Co Ltd A23
- ☐ Wharton Crane & Hoist Co Ltd, The A20

Metals, fabrication, machining, machinery and products
- ☐ Atkinson Ltd, D. & J. M. A74
- ☐ Allen & Sons (Tipton) Ltd, W. G. A70
- ☐ Armstrong Whitworth Aircraft Ltd, Sir W. G. A72
- ☐ Atlas Steel Foundry & Eng Co Ltd A71
- ☐ Barker & Sons (Eng) Ltd, J. A80
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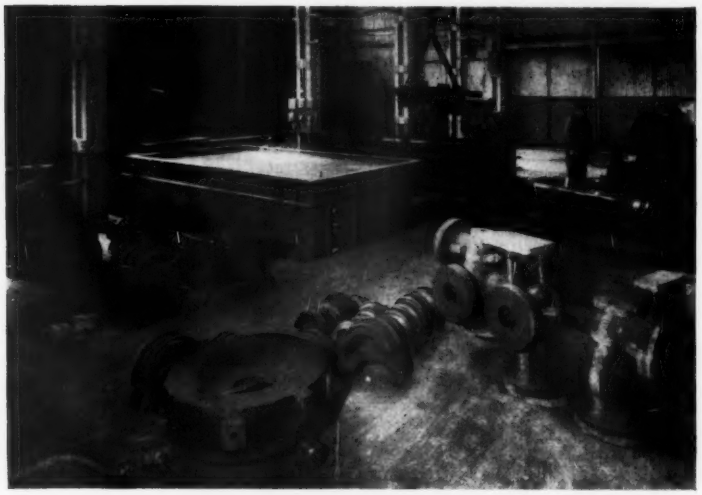

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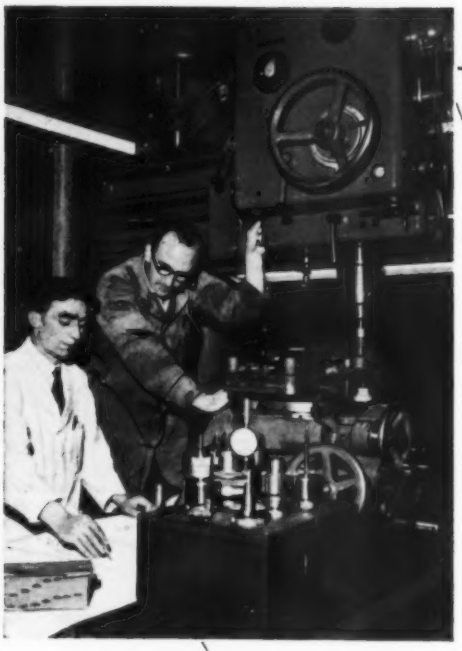

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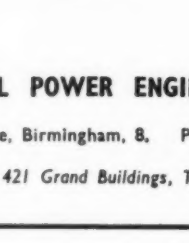

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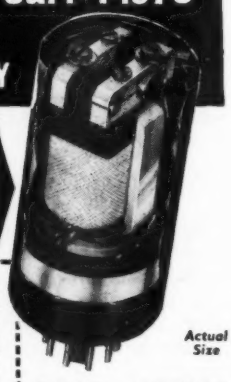

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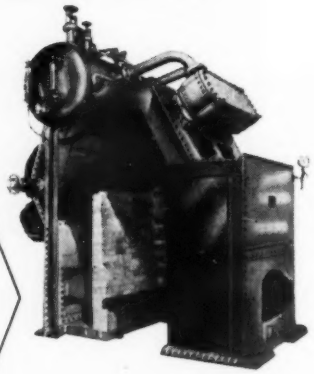

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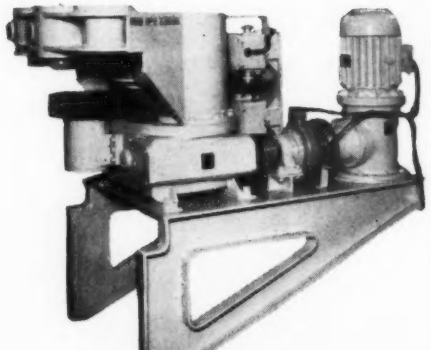

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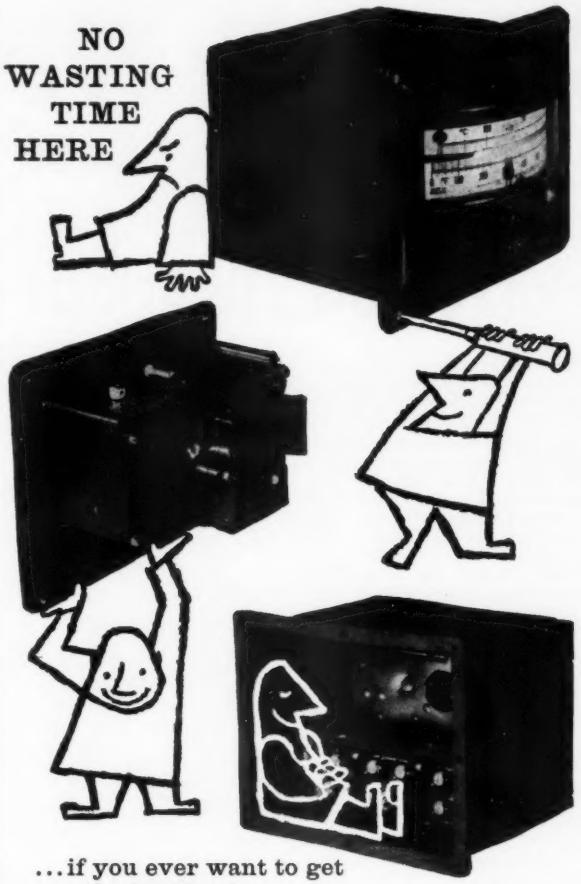

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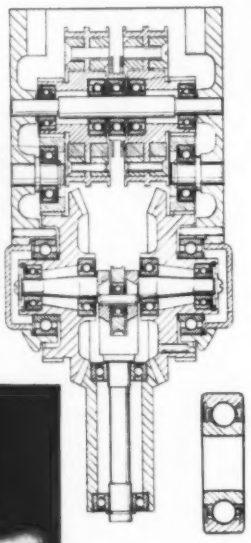

ABOVE Bearing layout for the "wrist" assembly including an enlarged view of one of the shielded ball bearings.

LEFT Slave "hand" grasps and pours contents of bottle.

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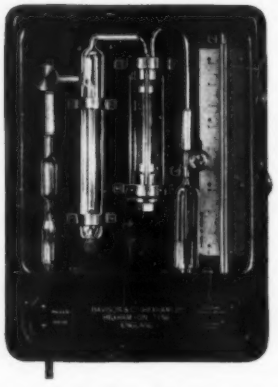

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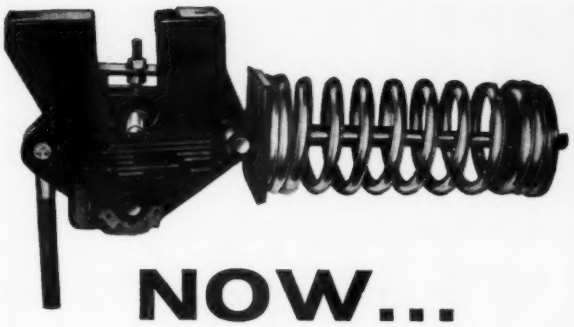

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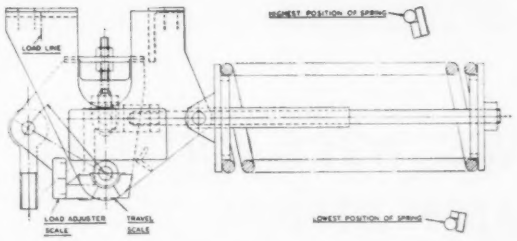

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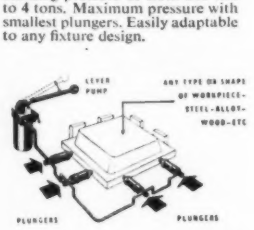

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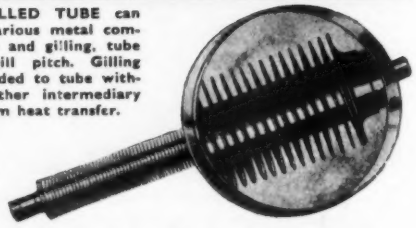

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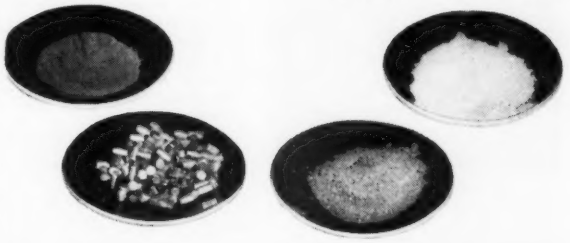

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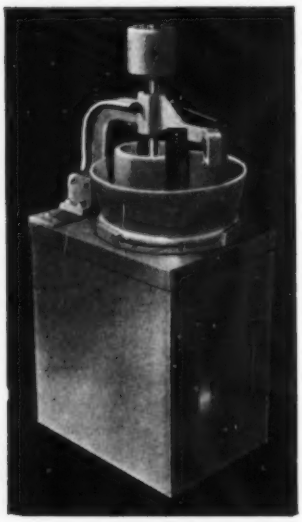

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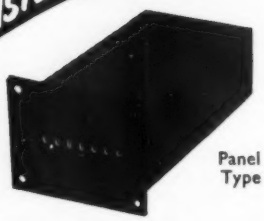

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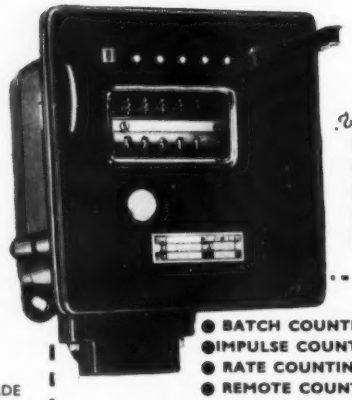

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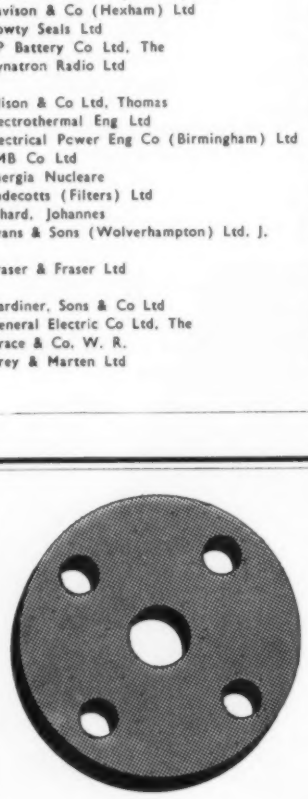

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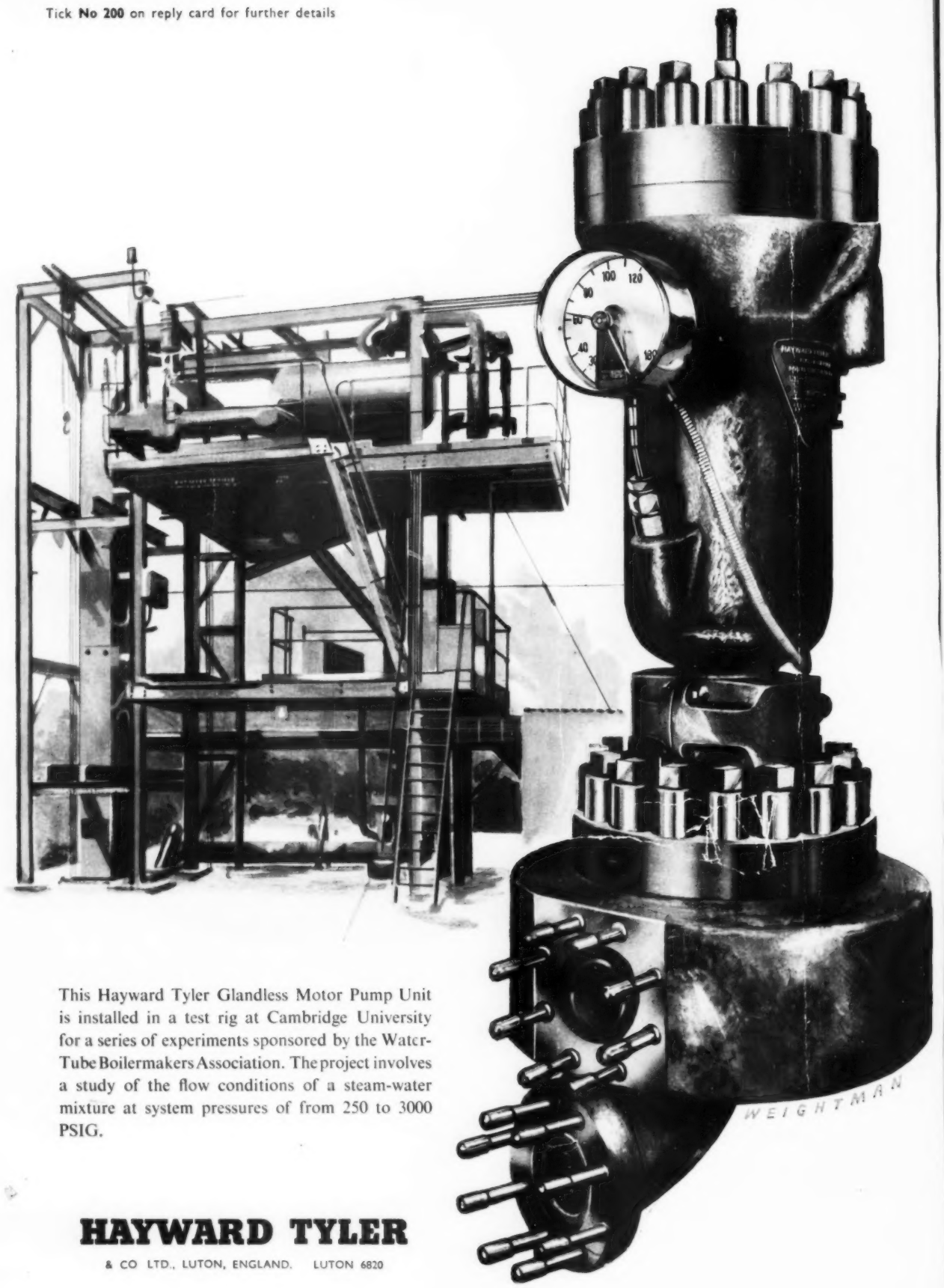

This Hayward Tyler Glandless Motor Pump Unit is installed in a test rig at Cambridge University for a series of experiments sponsored by the Water-Tube Boilermakers Association. The project involves a study of the flow conditions of a steam-water mixture at system pressures of from 250 to 3000 PSIG.

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